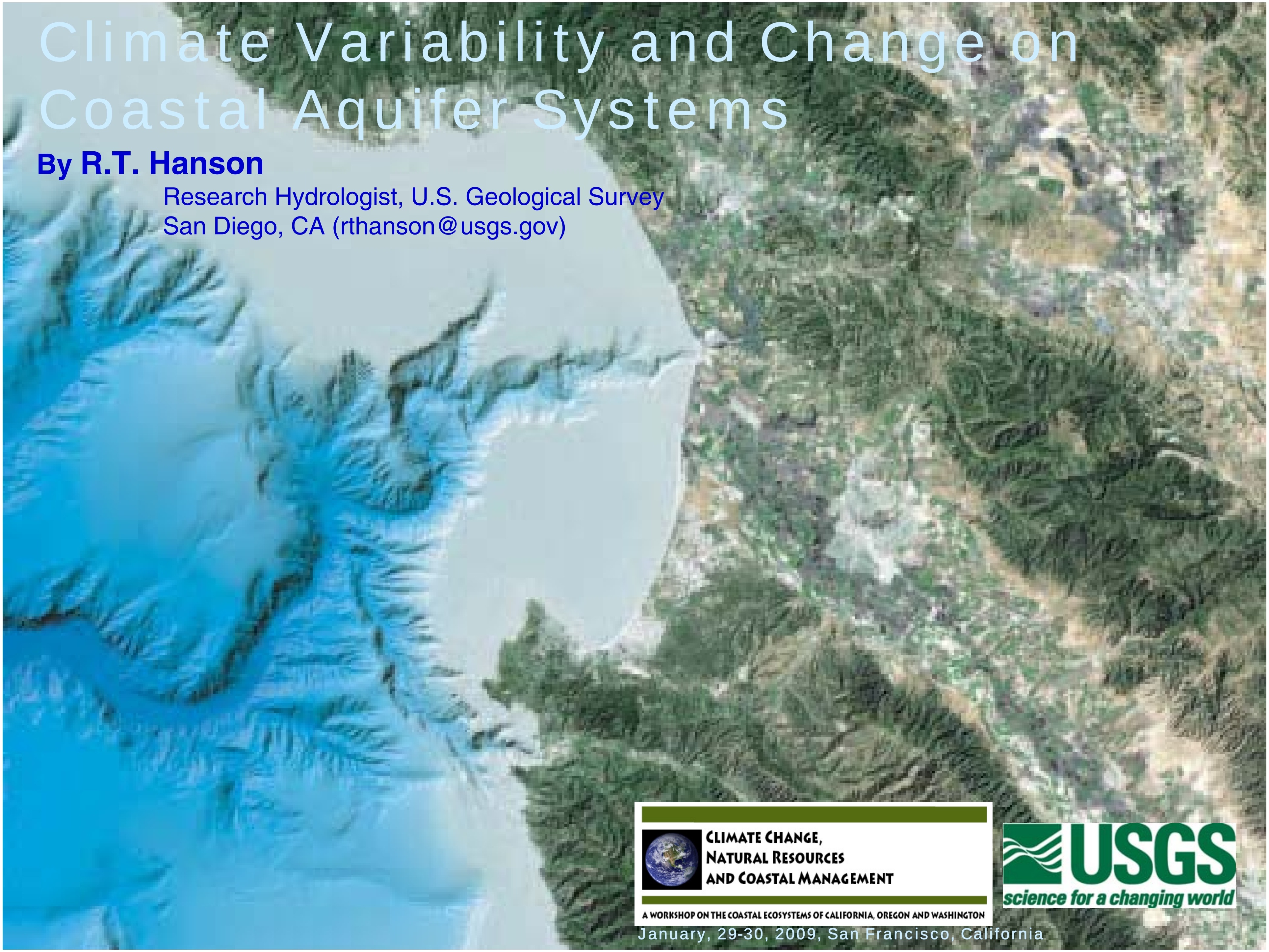

Climate Variability and Change on Coastal Aquifer Systems

By R.T. Hanson

Research Hydrologist, U.S. Geological Survey
San Diego, CA (rthanson@usgs.gov)

CLIMATE CHANGE,
NATURAL RESOURCES
AND COASTAL MANAGEMENT

A WORKSHOP ON THE COASTAL ECOSYSTEMS OF CALIFORNIA, OREGON AND WASHINGTON

USGS
science for a changing world

January, 29-30, 2009, San Francisco, California

Circum-Pacific Coastal Alluvial Basins → Agricultural and Urban Coastal Basins Development

- Changing Land Use
- Seawater Intrusion
- Land Subsidence
- Pumpage from Multi-aquifer Systems with wellbore flow
- Conjunctive Use of Ground-Water and Surface Water
- Artificial Recharge

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Major Coastal Issues

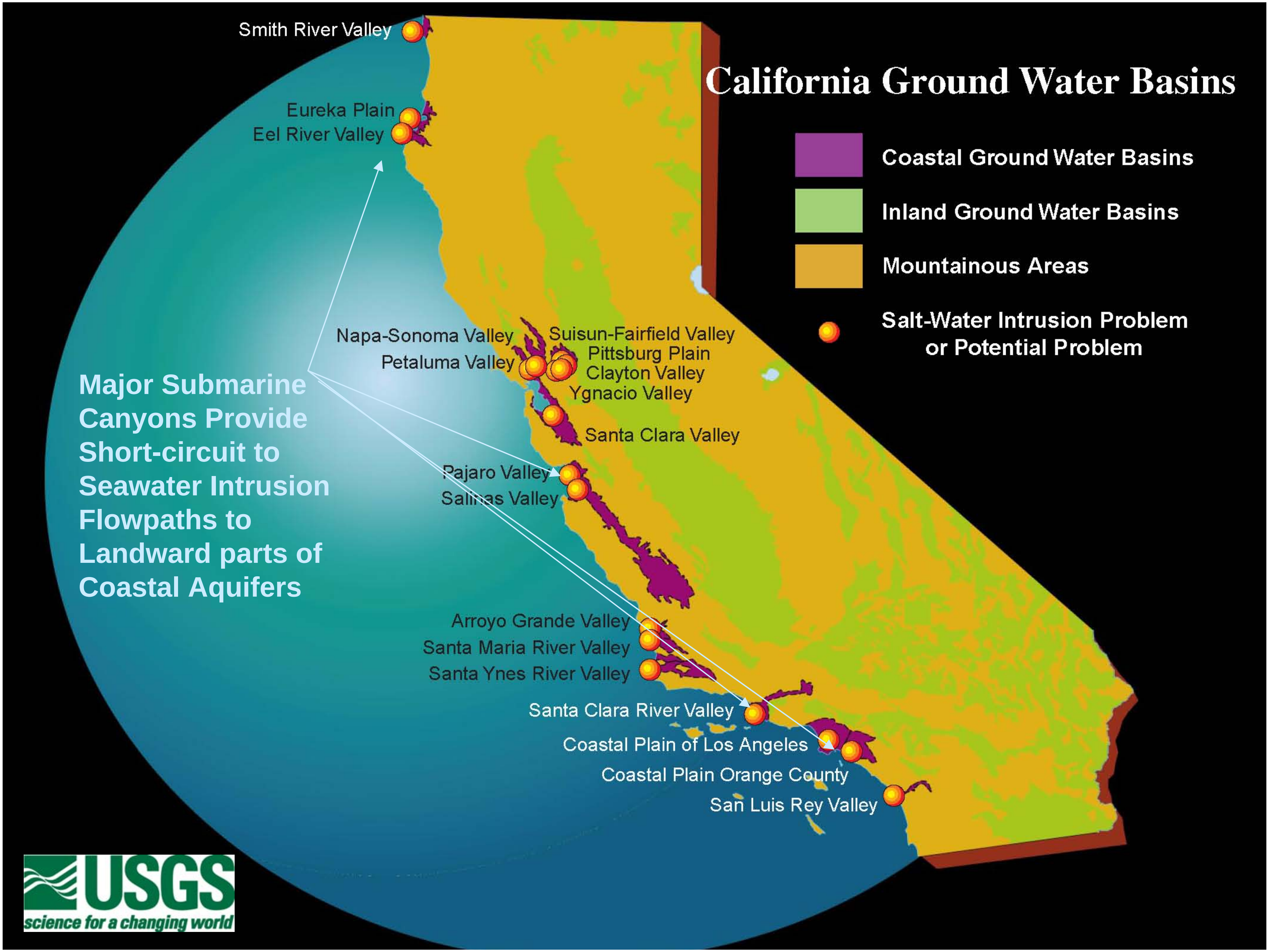
Climate Variability and Change will affect the hydrologic system and related land use for Coastal Watersheds that, in part, depend on ground-water resources for water supply and irrigation (Conjunctive Use).

- Pajaro Valley, Monterey Bay
- Santa Clara River Valley → Ventura-Oxnard Plain, SoCal
- Santa Clara Valley, South SF Bay

Work Performed with Funding from:
(1) California Application Project (CAP)
a NOAA/OGP Regional Integrated Sciences and Assessments (RISA) member
(2) USGS – WRD Global Climate Change Program

Coastal Development + Climate Change → Surface Coastal Problems

- Increased flooding of sewers and wastewater pollution control plants (WPCP) and a reduced ability to discharge Combined Sewer Overflows (CSO) and WPCP effluent by gravity
- High storm surge levels lead to more street, basement and sewer flooding and more damage from surge action
- Higher sea levels, when inundating polluted areas (brownfields), can cause harmful release of pollutants
- Higher sea levels can inundate fresh and saline wetlands and threaten the stability of canals and levee systems, which can have impacts on water supplies, water quality, and flooding.
- Rise in sea level will result in reduced sediment transport and demand increased dredging of sluices, weirs, gryones, locks, and canals and filling of wetland areas and heightening/enforcing of levees and embankments
- Higher sea levels may also impact other structural components that would impact shipping such as clearance of bridge heights and water depths in weirs


California Ground Water Basins
Coastal Ground Water Basins
Inland Ground Water Basins
Mountainous Areas
Salt-Water Intrusion Problem or Potential Problem
Major Submarine Canyons Provide Short-circuit to Seawater Intrusion Flowpaths to Landward parts of Coastal Aquifers
Smith River Valley
Eureka Plain
Eel River Valley
Napa-Sonoma Valley
Petaluma Valley
Suisun-Fairfield Valley
Pittsburg Plain
Clayton Valley
Ygnacio Valley
Santa Clara Valley
Pajaro Valley
Salinas Valley
Arroyo Grande Valley
Santa Maria River Valley
Santa Ynes River Valley
Santa Clara River Valley
Coastal Plain of Los Angeles
Coastal Plain Orange County
San Luis Rey Valley
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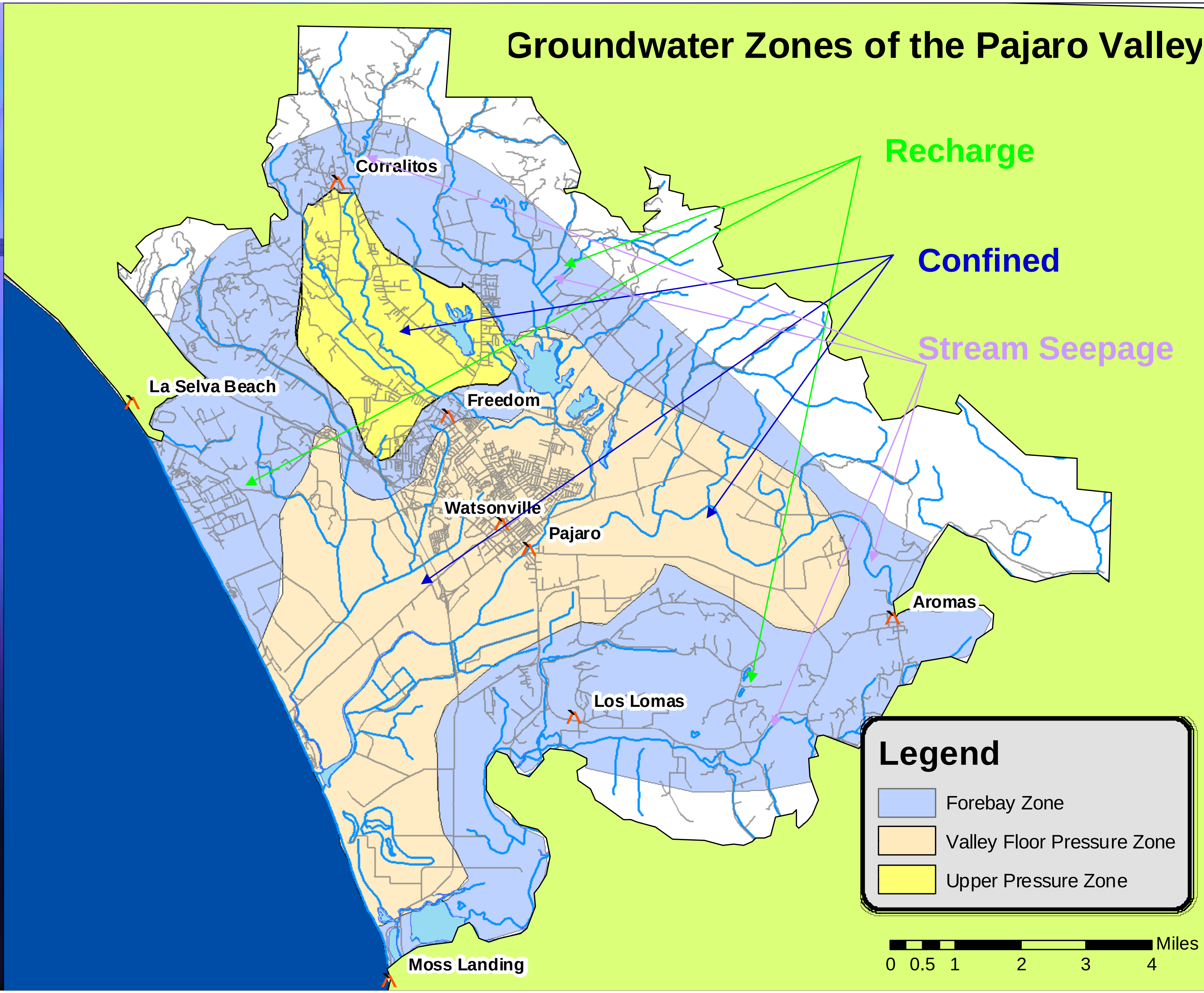
Groundwater Zones of the Pajaro Valley



Groundwater Overdraft

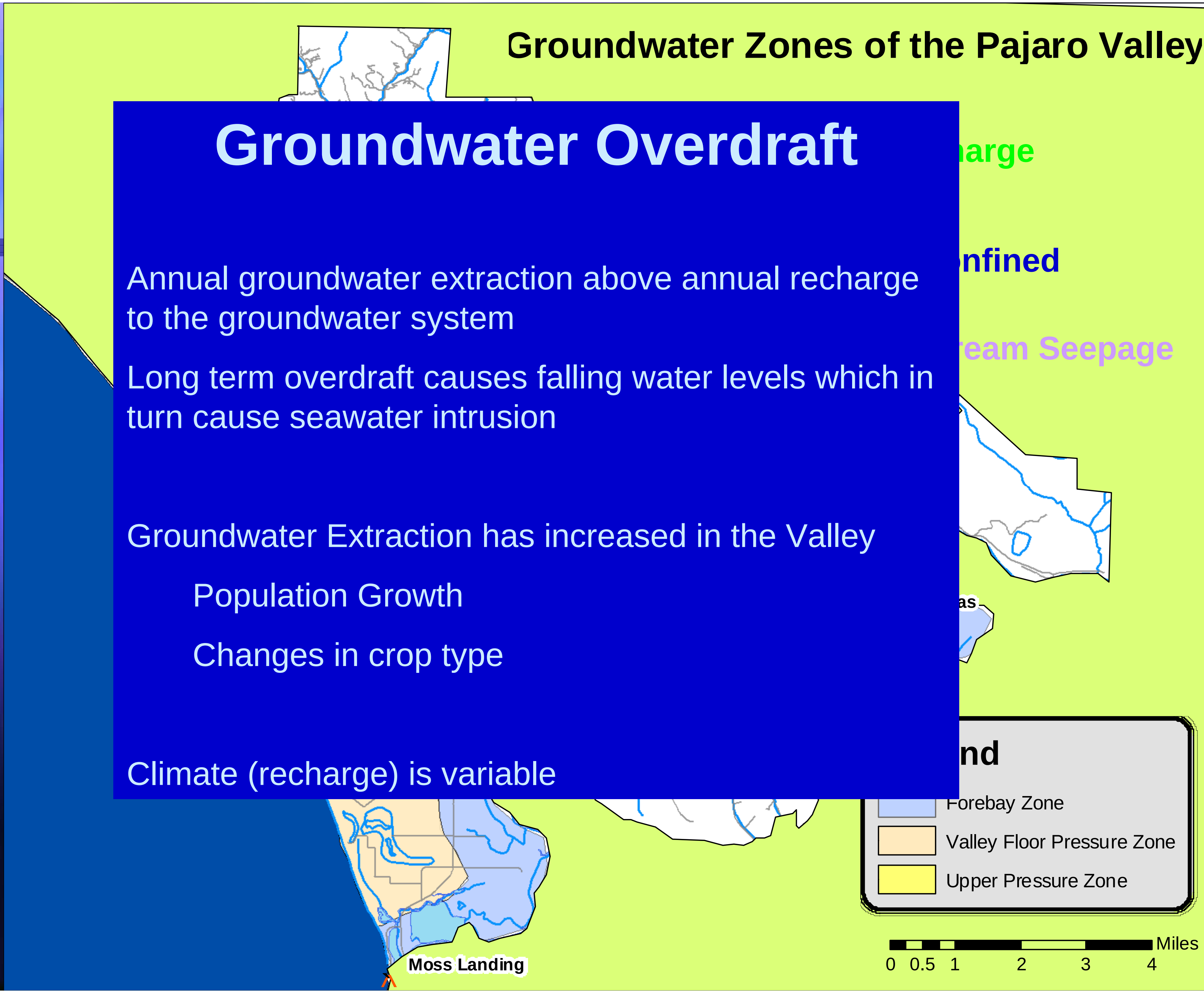
Annual groundwater extraction above annual recharge to the groundwater system

Long term overdraft causes falling water levels which in turn cause seawater intrusion

Groundwater Extraction has increased in the Valley

- Population Growth
- Changes in crop type

Climate (recharge) is variable



Number of Layers Well Screens Penetrate

N

Explanation

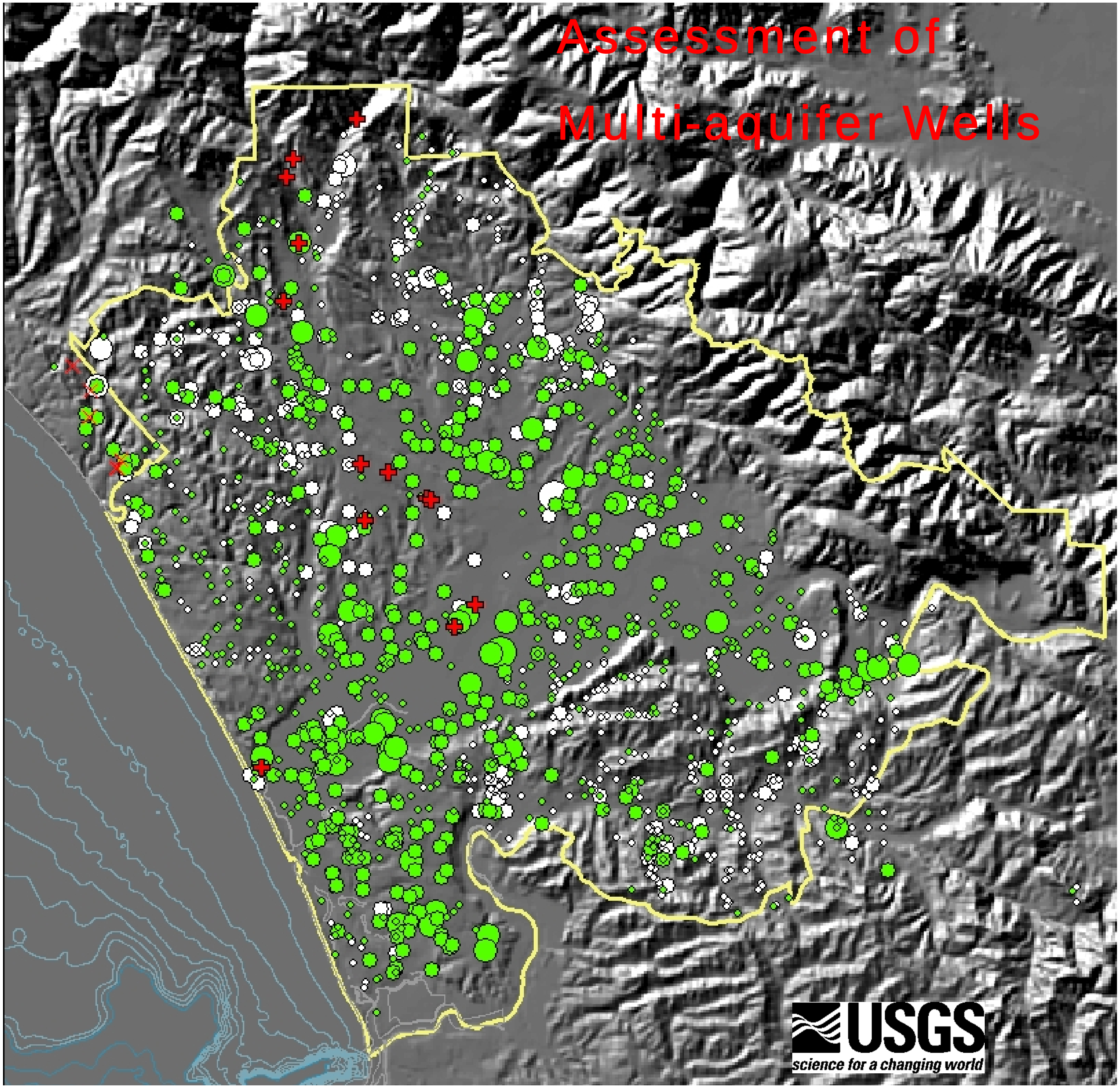
- Soquel Creek wells
- Watsonville wells

farm wells

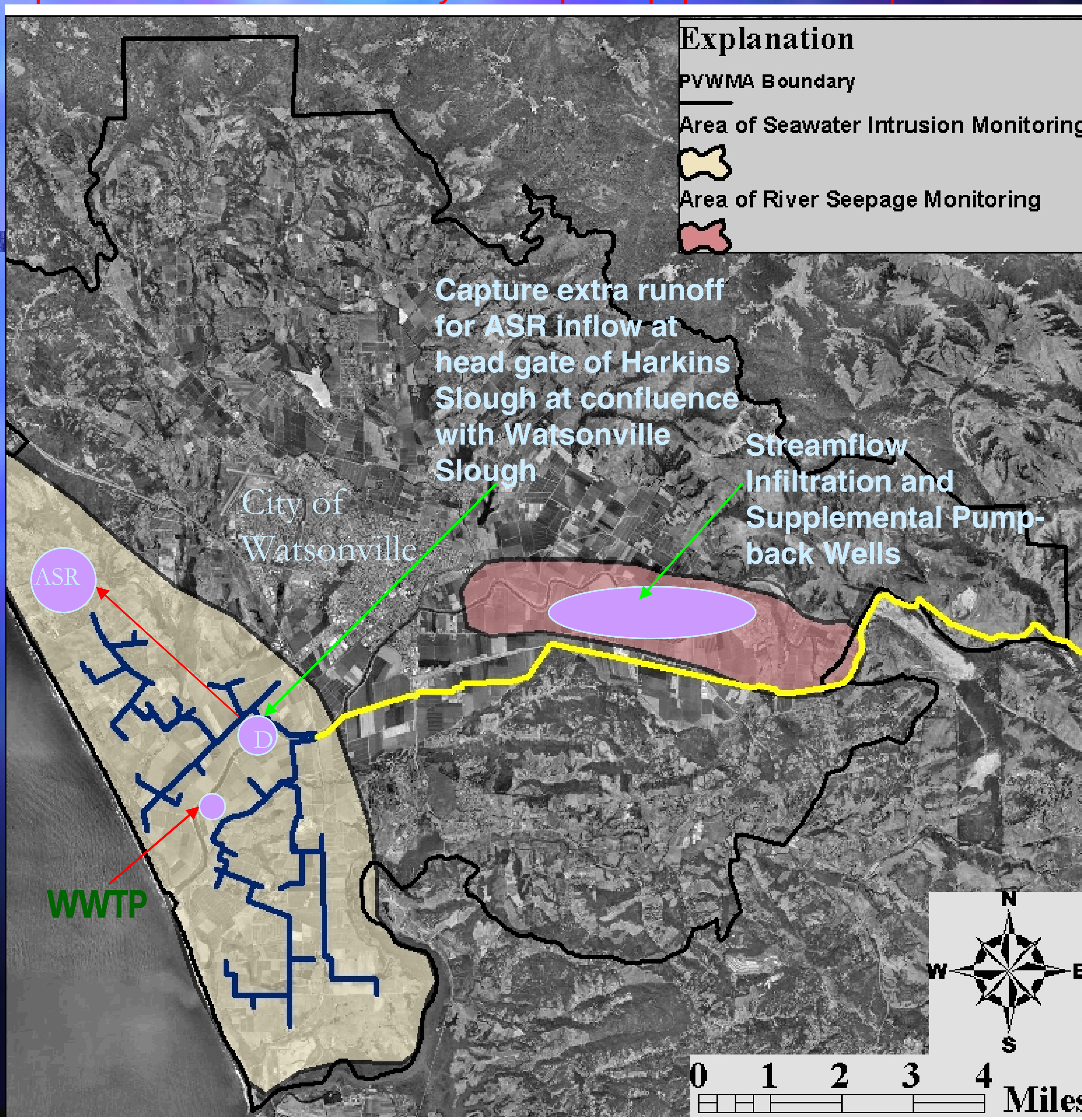
- 1
- 2
- 3
- 4 - 5

domestic wells

- 1
- 2
- 3
- 4 - 5



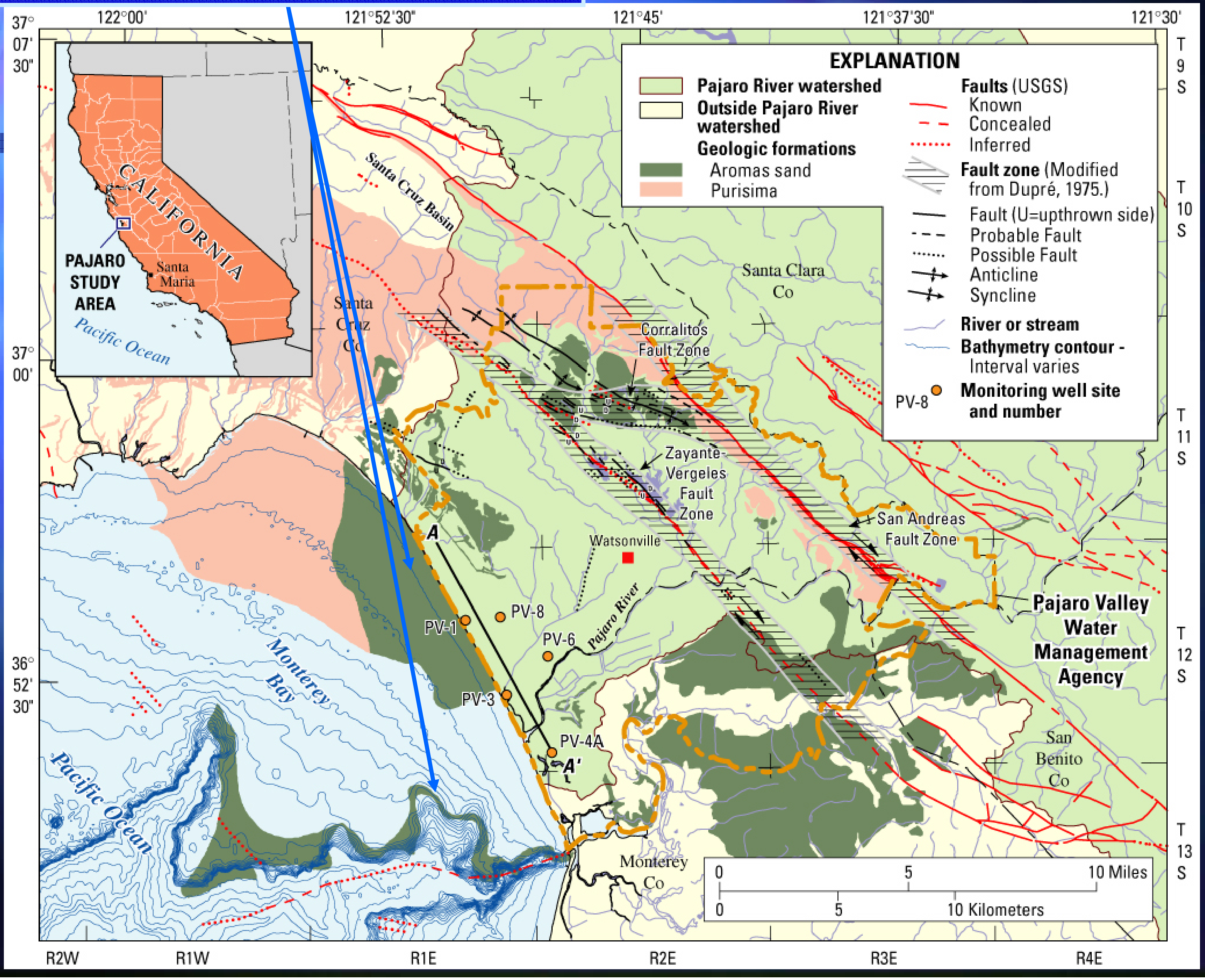
Proposed coastal delivery & import pipeline components of BMP projects

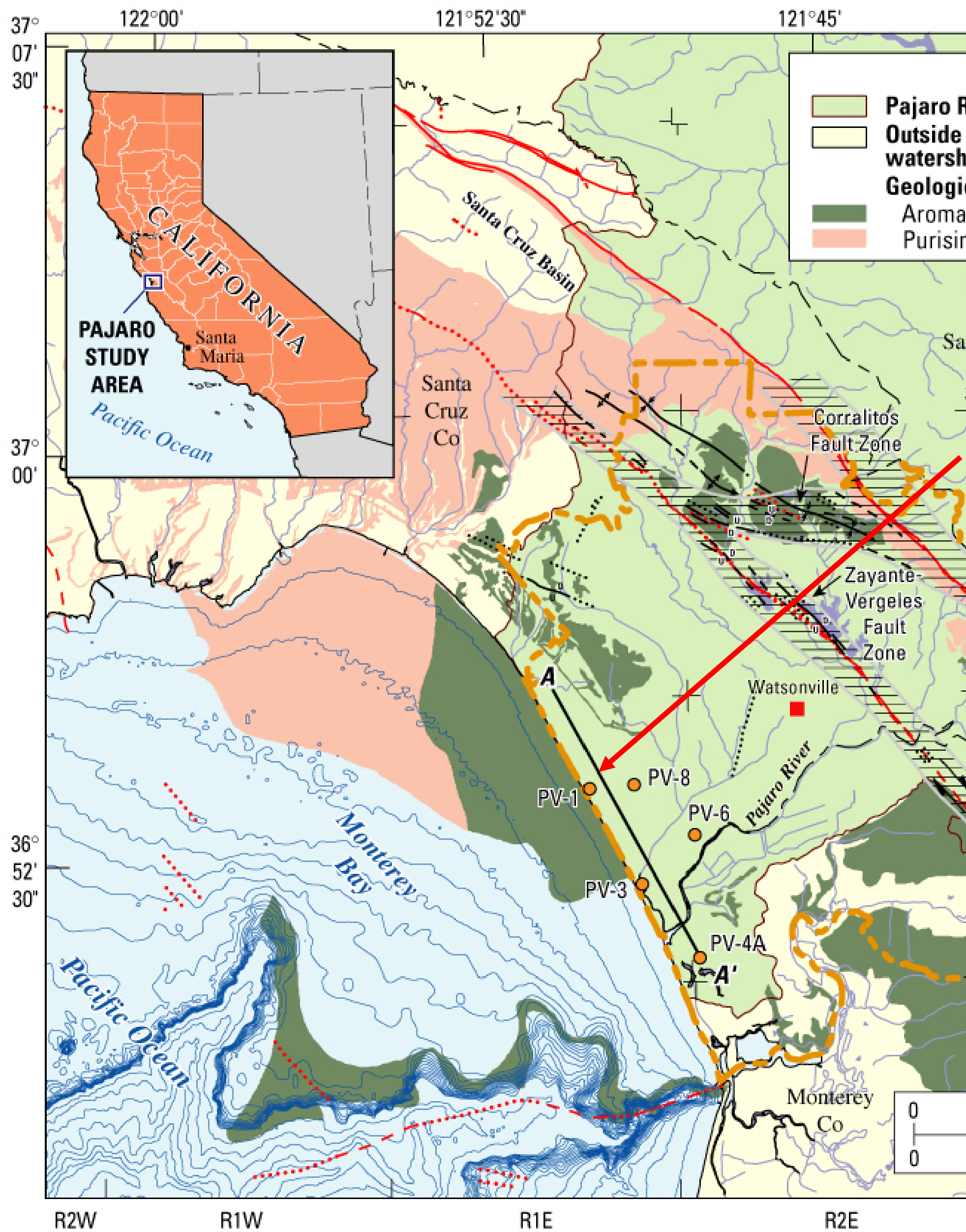


Developing Scheme for integrating Harkins Slough Diversion/ASR and CDS within FMP/SFR simulation in PVMF2K

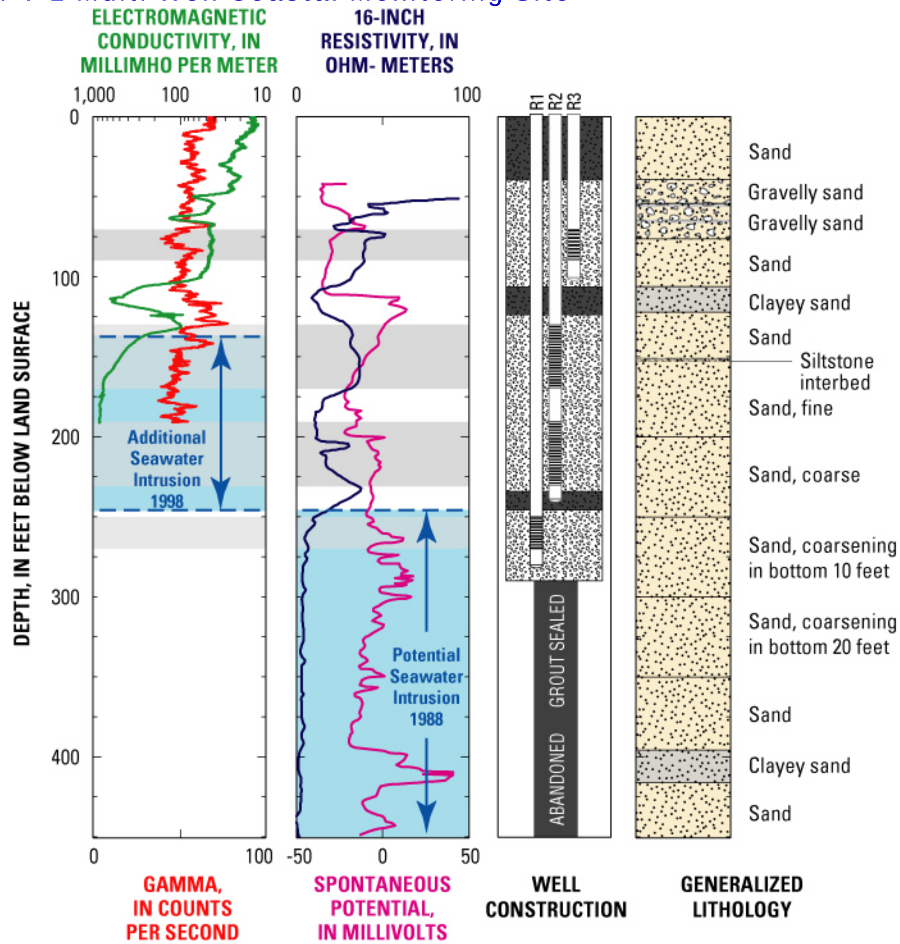
Split CDS into pieces that are aligned with Water-Balance subregions

Sources of Seawater Intrusion to Pajaro Groundwater Basin





PV-1 Multi-Well Coastal Monitoring Site



Recent Seawater Intrusion ~60% based on stable isotopes

Pajaro Valley Shows Multiple Types of Seawater Intrusion

Global Climate Change 4.9 ft (1.5 m) rise in Sea Level → Additional Seawater Intrusion

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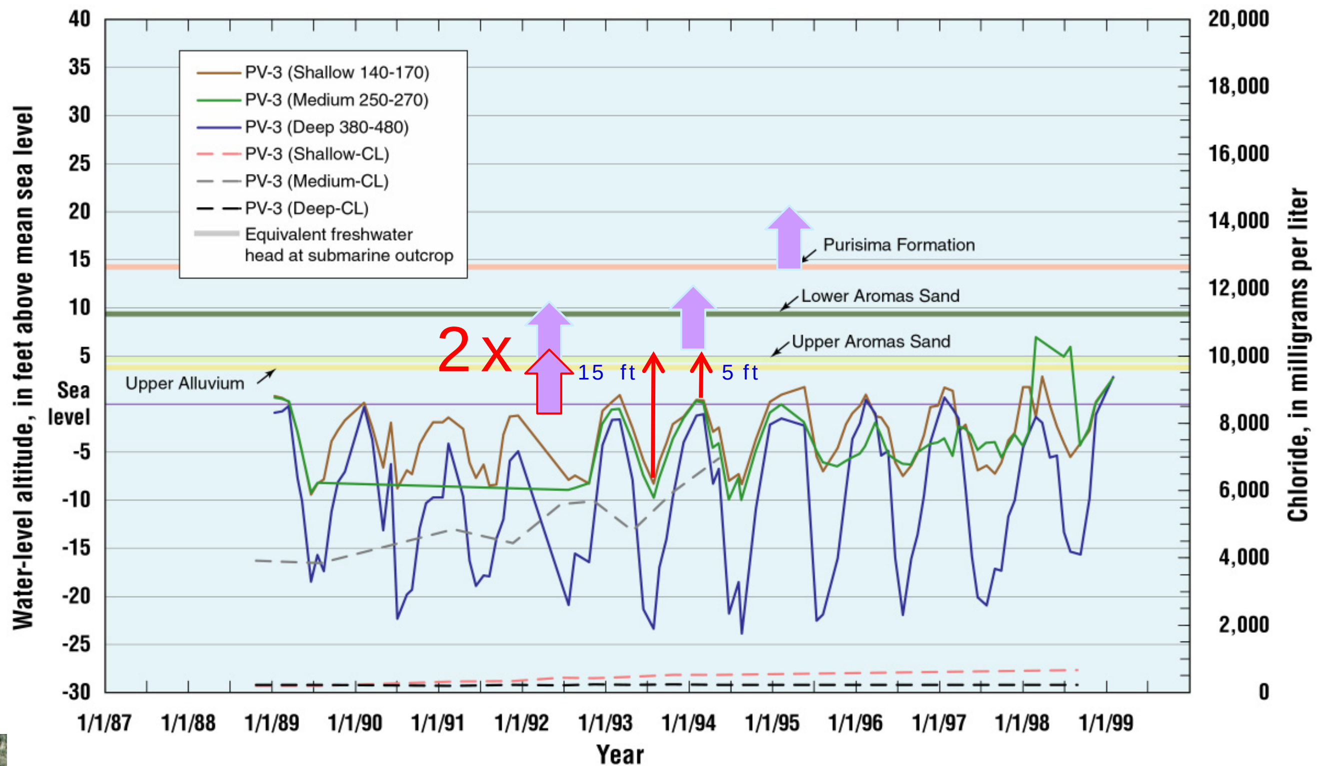
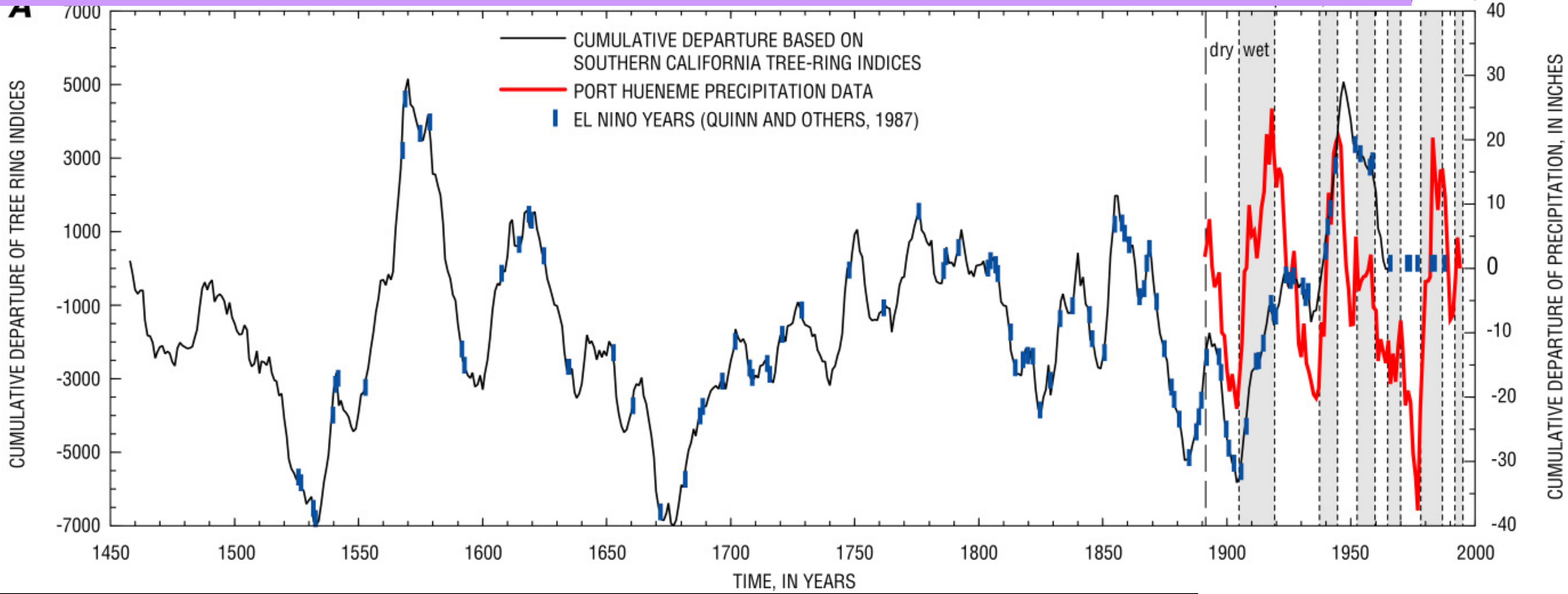
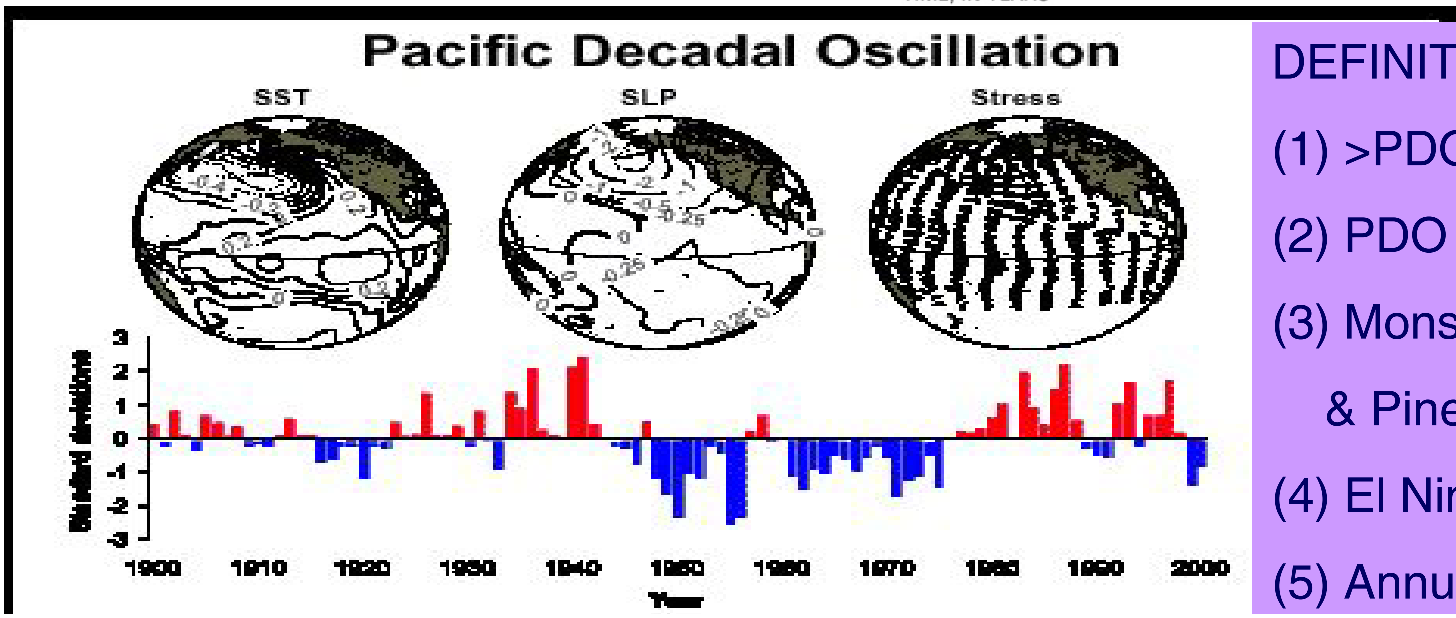
Water Levels and Sea Water Intrusion



- Long term declines, climatic cycles, and seasonal pumping suppress water levels below sea water pressures allowing sea water to flow inland and contaminate fresh ground water supplies
- Not all intrusion is saline waters but some is very old water possibly being forced landward from offshore, i.e PV-3 (Deep)

Relation between Tree-Ring Indices, El Nino's, and Precipitation





DEFINITION OF FORCINGS

(1) >PDO ➔ AMO >25yr

(2) PDO 10-25 yr

(3) Monsoonal Flow 7-10yr

& Pineapple Express

(4) El Nino(ENSO) 2-7yr

(5) Annual 1-2yr

Floods continue to occur Periodically

Climate Variability of Streamflow largely driven by PDO cycles but also show variation from other climate cycles

(California History Center, 1981)

Periodic Major Floods ➔ 1862, 1895, 1911, 1955, 1982-83,

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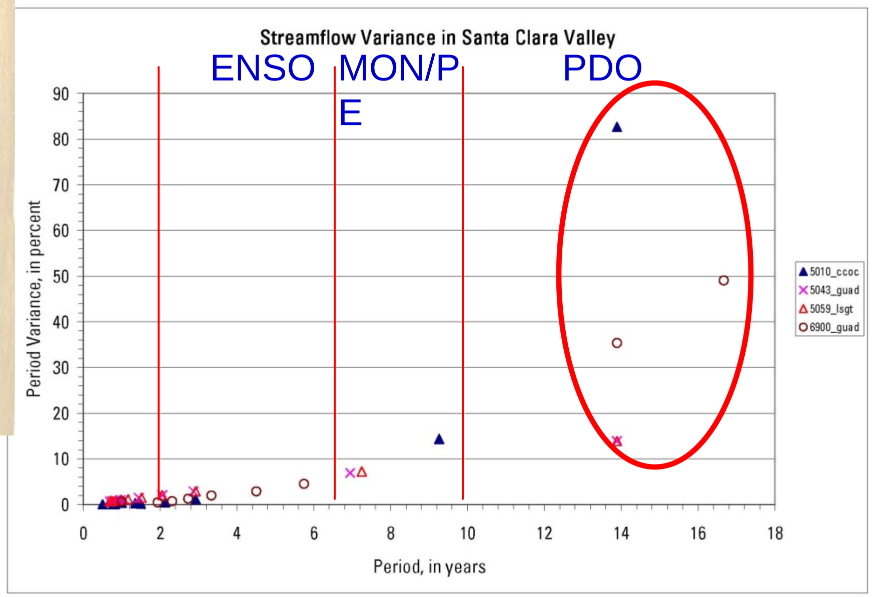
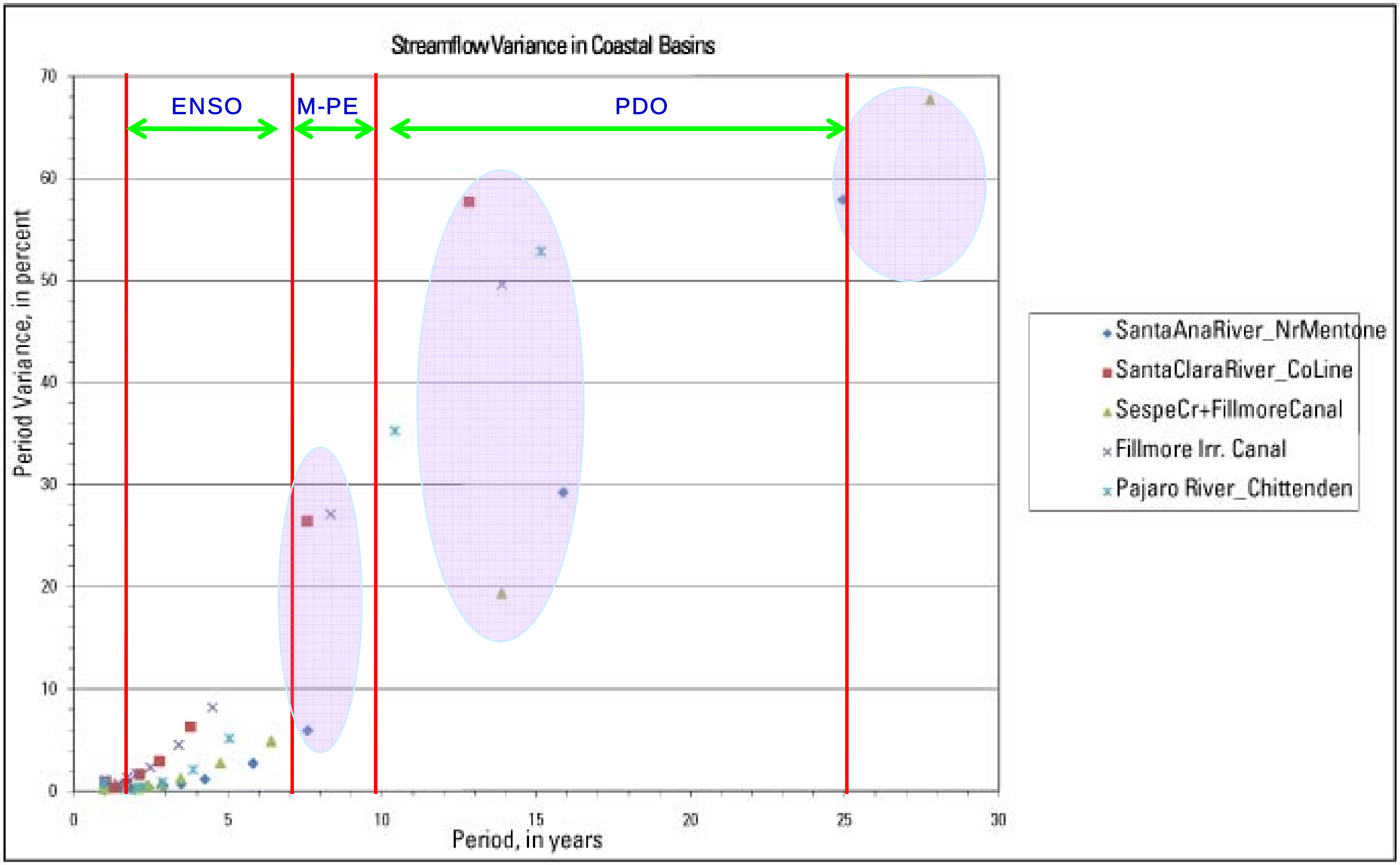
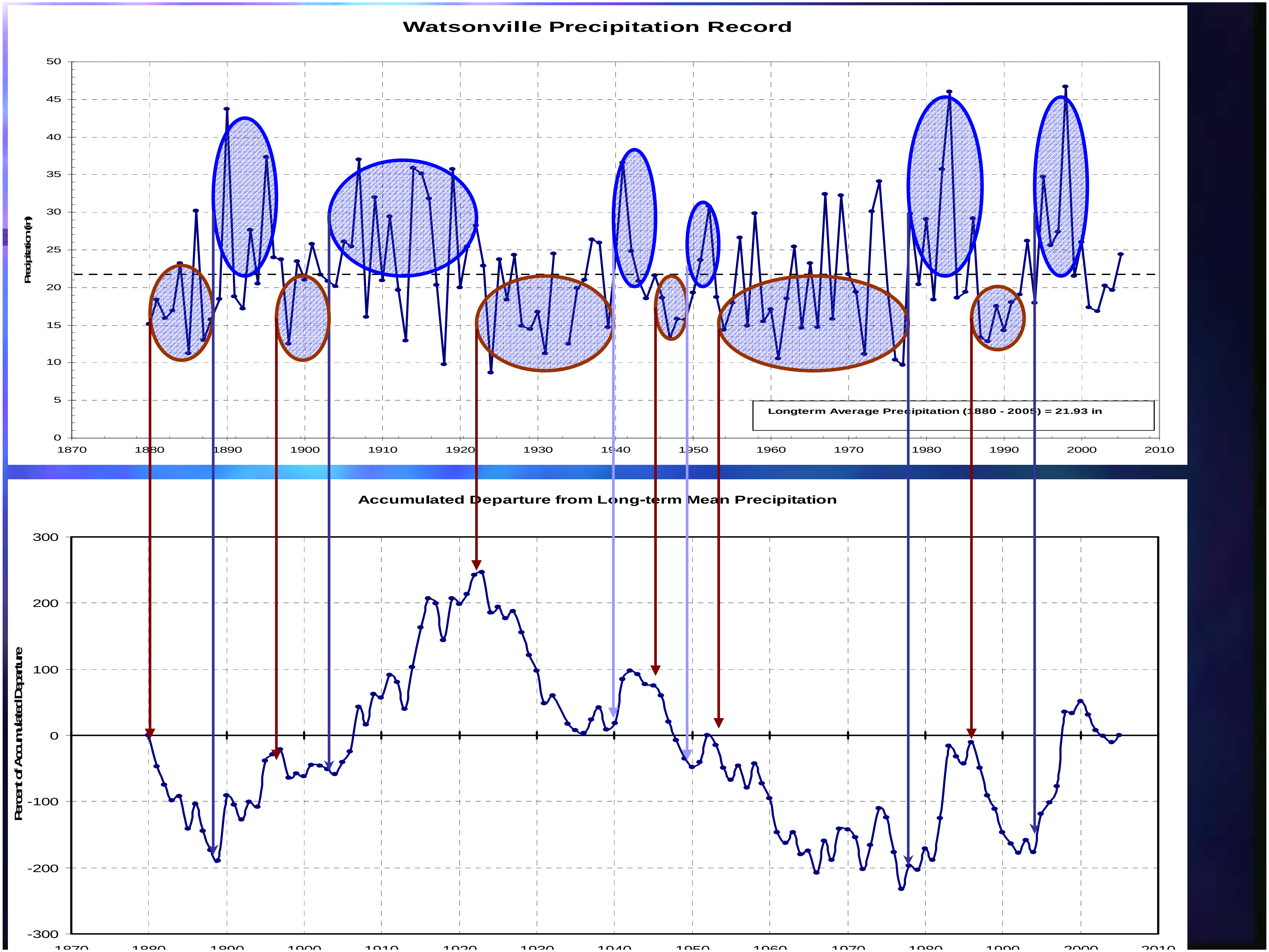


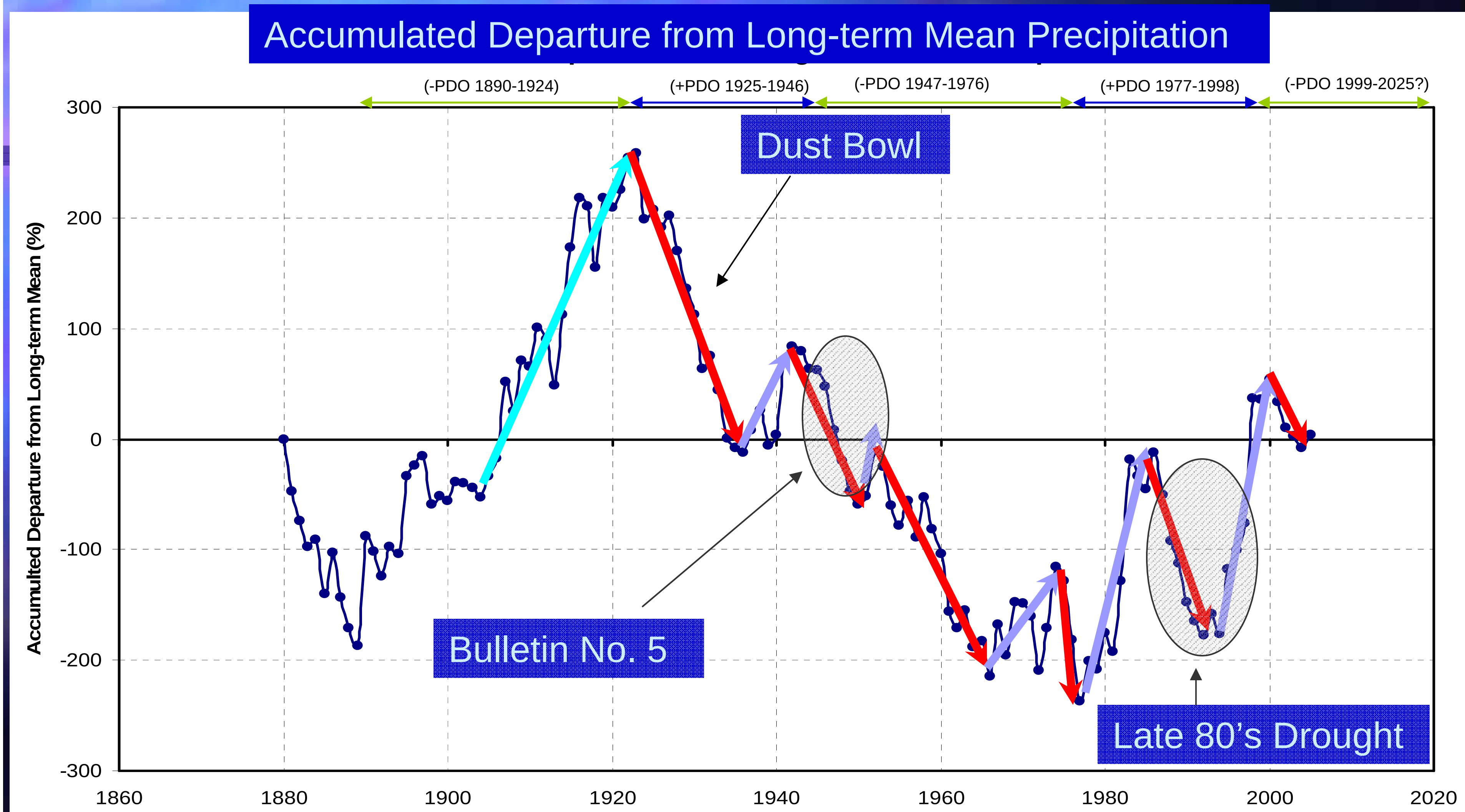


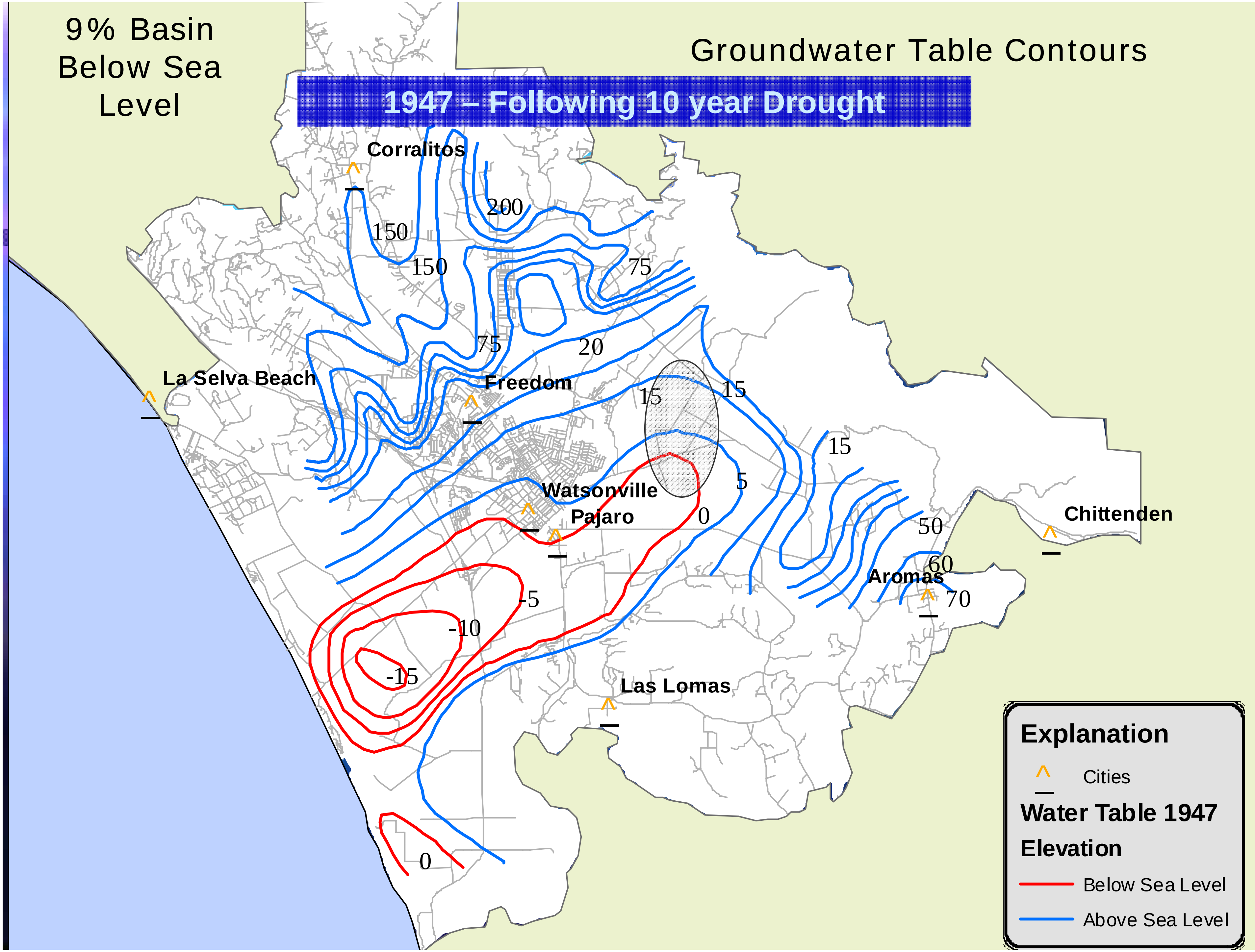
Streamflow Variance in Coastal Basins
ENSO
M-PE
PDO
Period Variance, in percent
Period, in years
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30
SantaAnaRiver_NrMentone
SantaClaraRiver_CoLine
SespeCr+FillmoreCanal
Fillmore Irr. Canal
Pajaro River_Chittenden



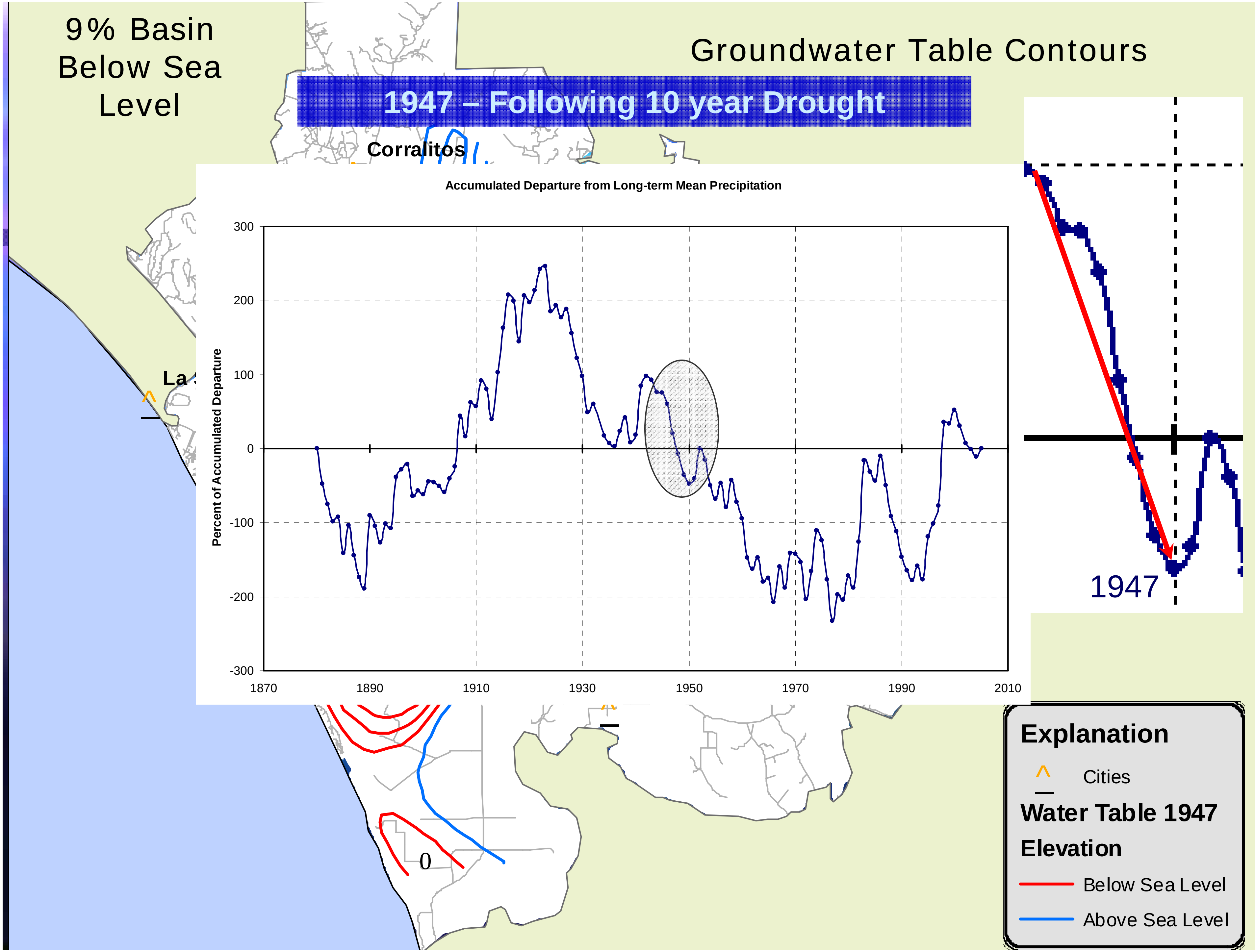
Watsonville Precipitation Record
Precipitation (in)
50
45
40
35
30
25
20
15
10
5
0
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Longterm Average Precipitation (1880 - 2005) = 21.93 in
Accumulated Departure from Long-term Mean Precipitation
Percent of Accumulated Departure
300
200
100
0
-100
-200
-300

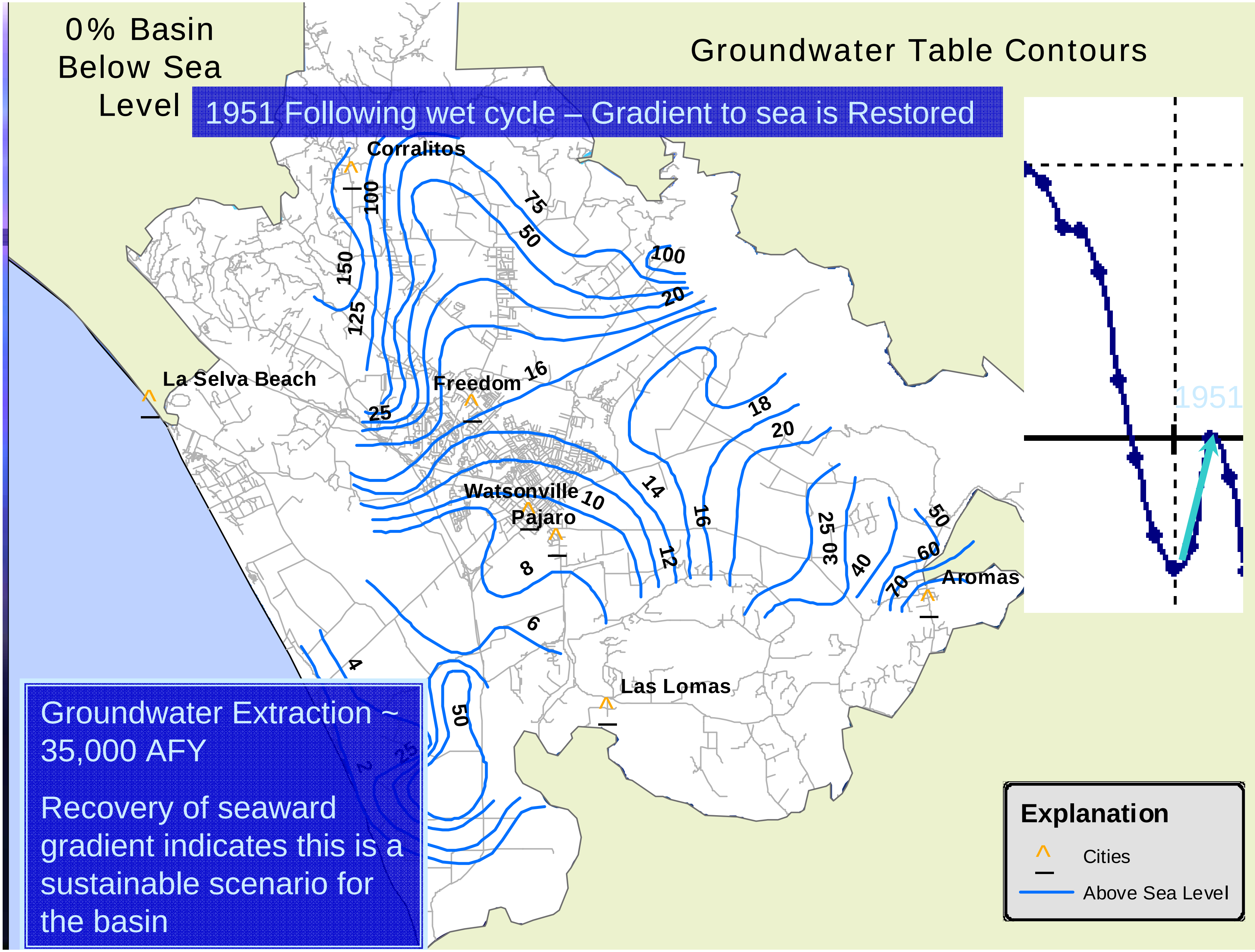
Climate Provides Input to Water Cycle



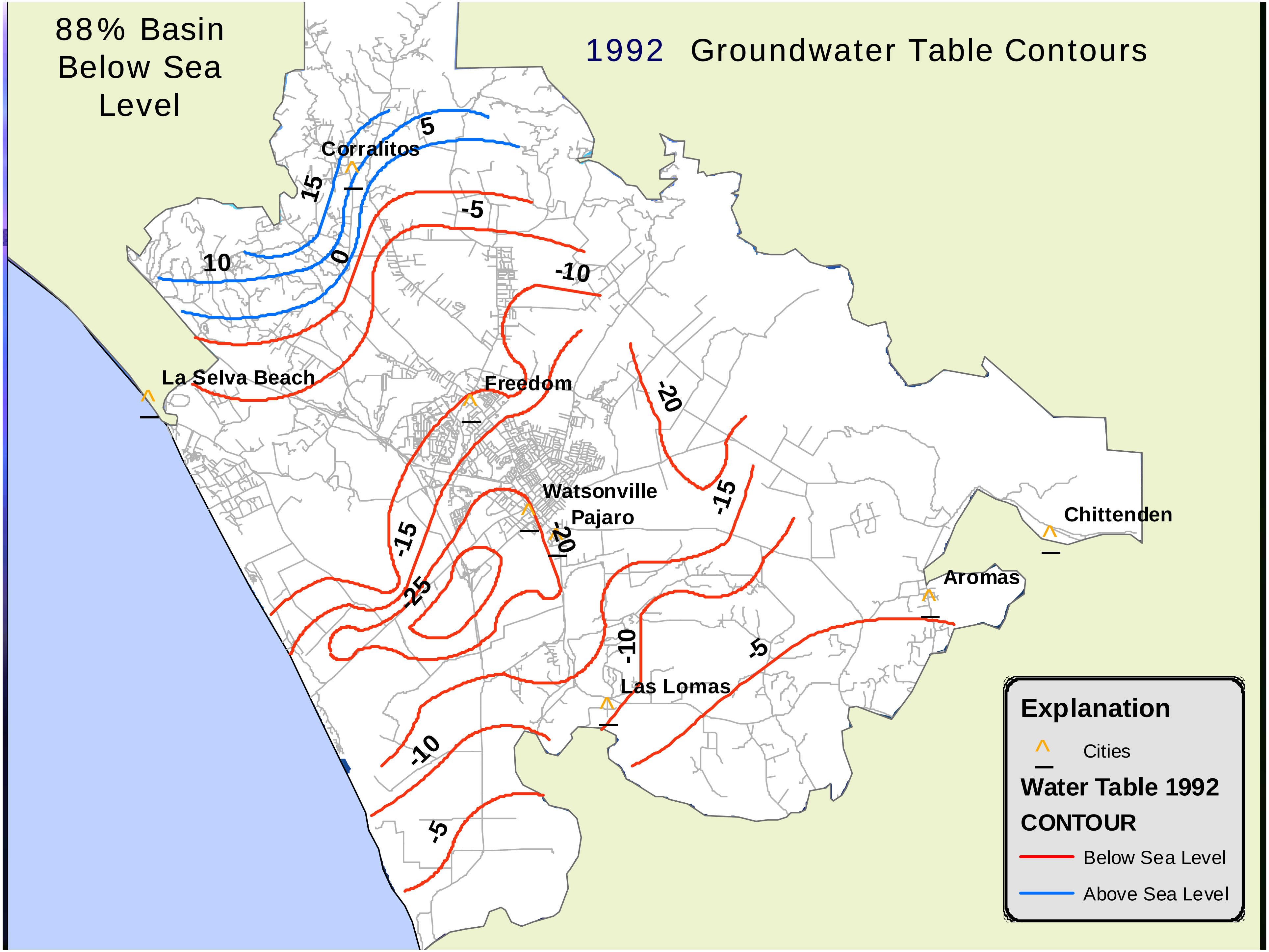


9% Basin Below Sea Level
Groundwater Table Contours
1947 – Following 10 year Drought
Corralitos
200
150
150
75
75
20
La Selva Beach
Freedom
15
15
15
5
0
Watsonville
Pajaro
50
60
70
Aromas
Chittenden
-5
-10
-15
Las Lomas
0
Explanation
Cities
Water Table 1947 Elevation
Below Sea Level
Above Sea Level


9% Basin Below Sea Level
Groundwater Table Contours
1947 – Following 10 year Drought
Corralitos
La
Accumulated Departure from Long-term Mean Precipitation
Percent of Accumulated Departure
300
200
100
0
-100
-200
-300
1870
1890
1910
1930
1950
1970
1990
2010
1947
0
Explanation
Cities
Water Table 1947 Elevation
Below Sea Level
Above Sea Level



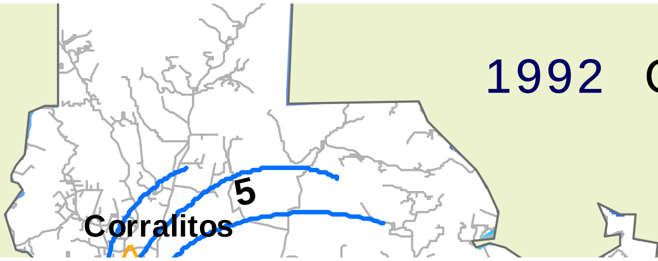
0% Basin Below Sea Level
Groundwater Table Contours
1951 Following wet cycle – Gradient to sea is Restored
Corralitos
La Selva Beach
Freedom
Watsonville
Pajaro
Aromas
Las Lomas
150
125
100
75
50
25
20
18
16
14
12
10
8
6
4
30
40
60
70
1951
Groundwater Extraction ~ 35,000 AFY
Recovery of seaward gradient indicates this is a sustainable scenario for the basin
Explanation
Cities
Above Sea Level

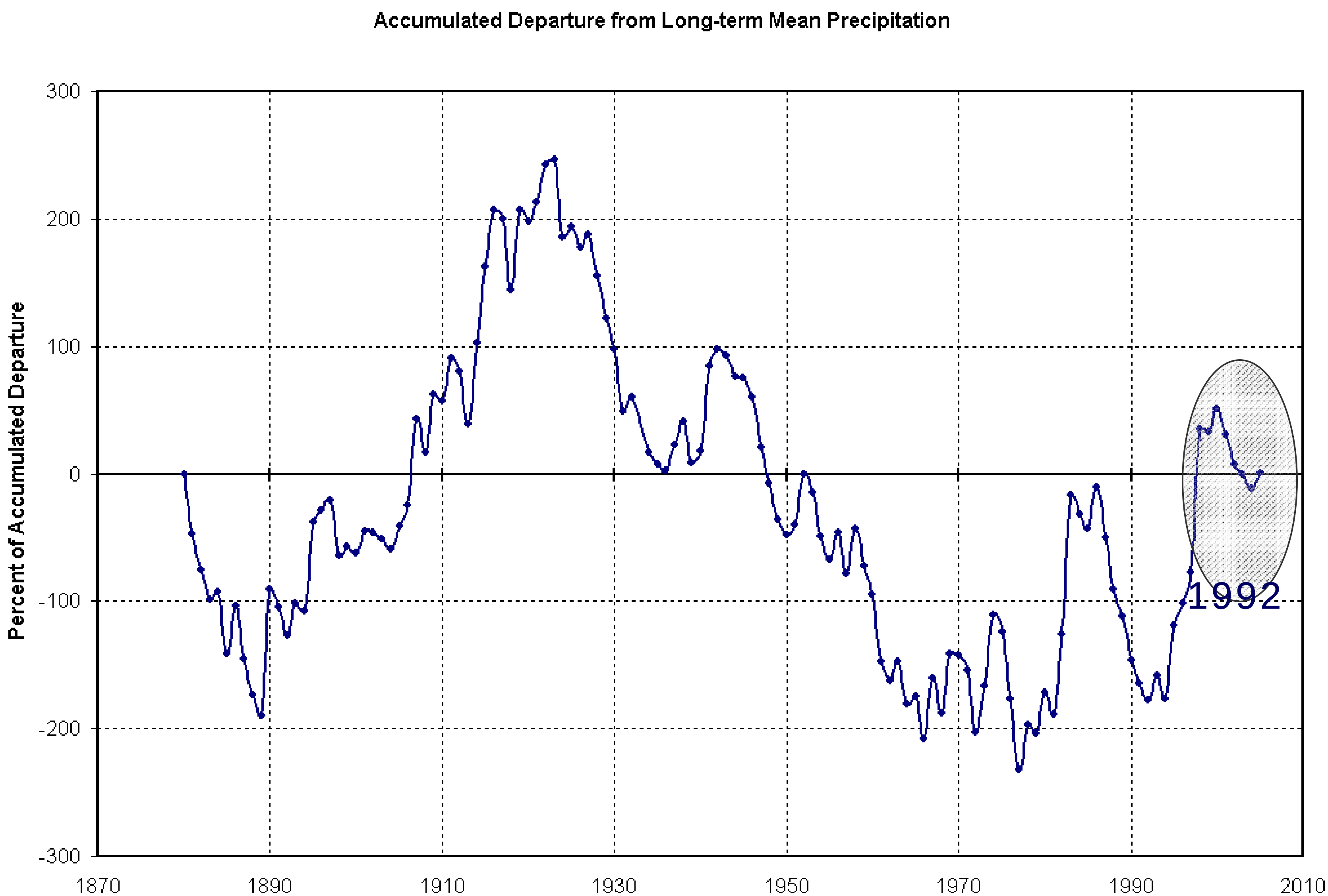


88% Basin Below Sea Level
1992 Groundwater Table Contours
Corralitos
La Selva Beach
Freedom
Watsonville
Pajaro
Chittenden
Aromas
Las Lomas
5
15
0
10
-5
-10
-15
-20
-25
Explanation
Cities
Water Table 1992
CONTOUR
Below Sea Level
Above Sea Level

88% Basin Below Sea Level

1992 Groundwater Table Contours





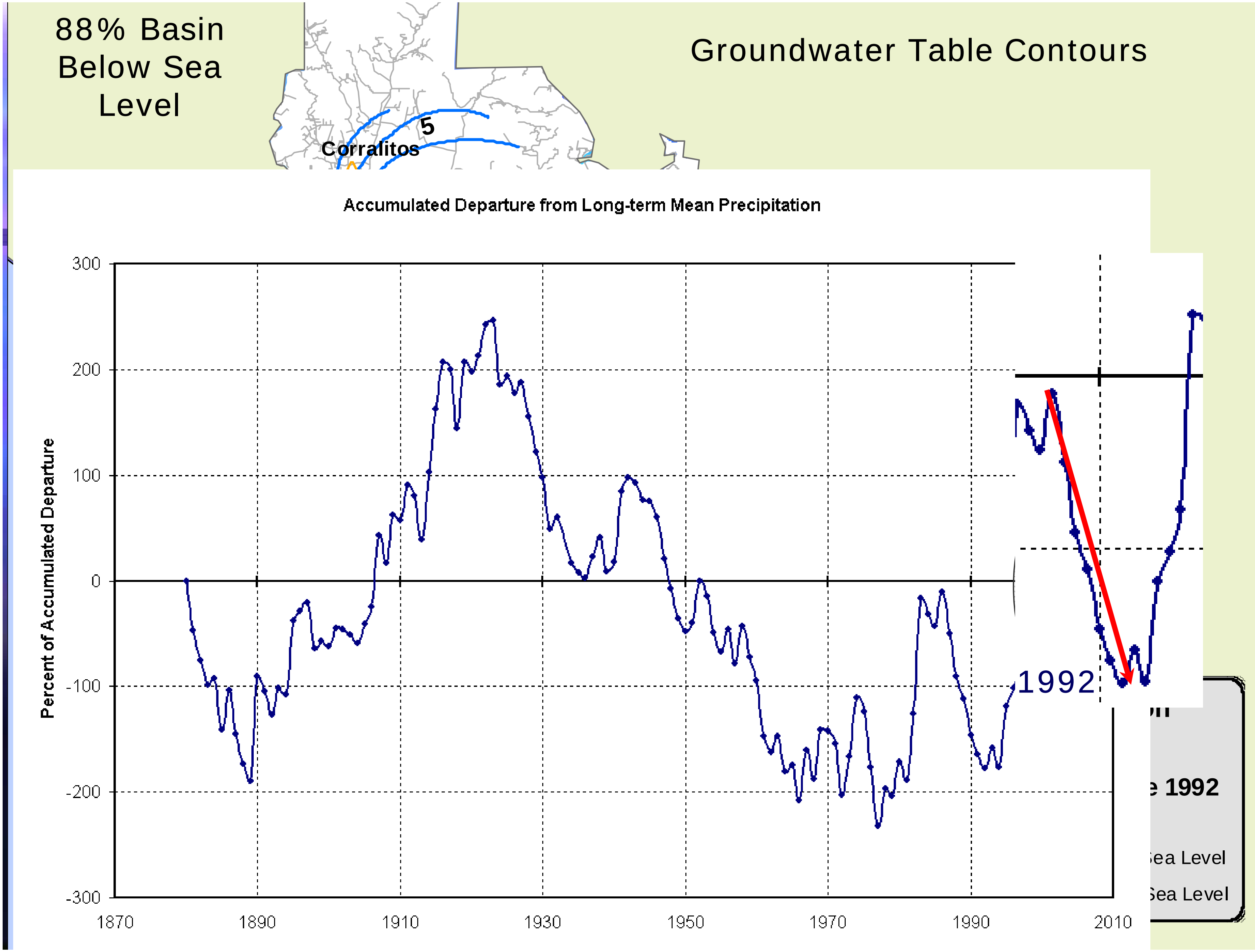
en

on

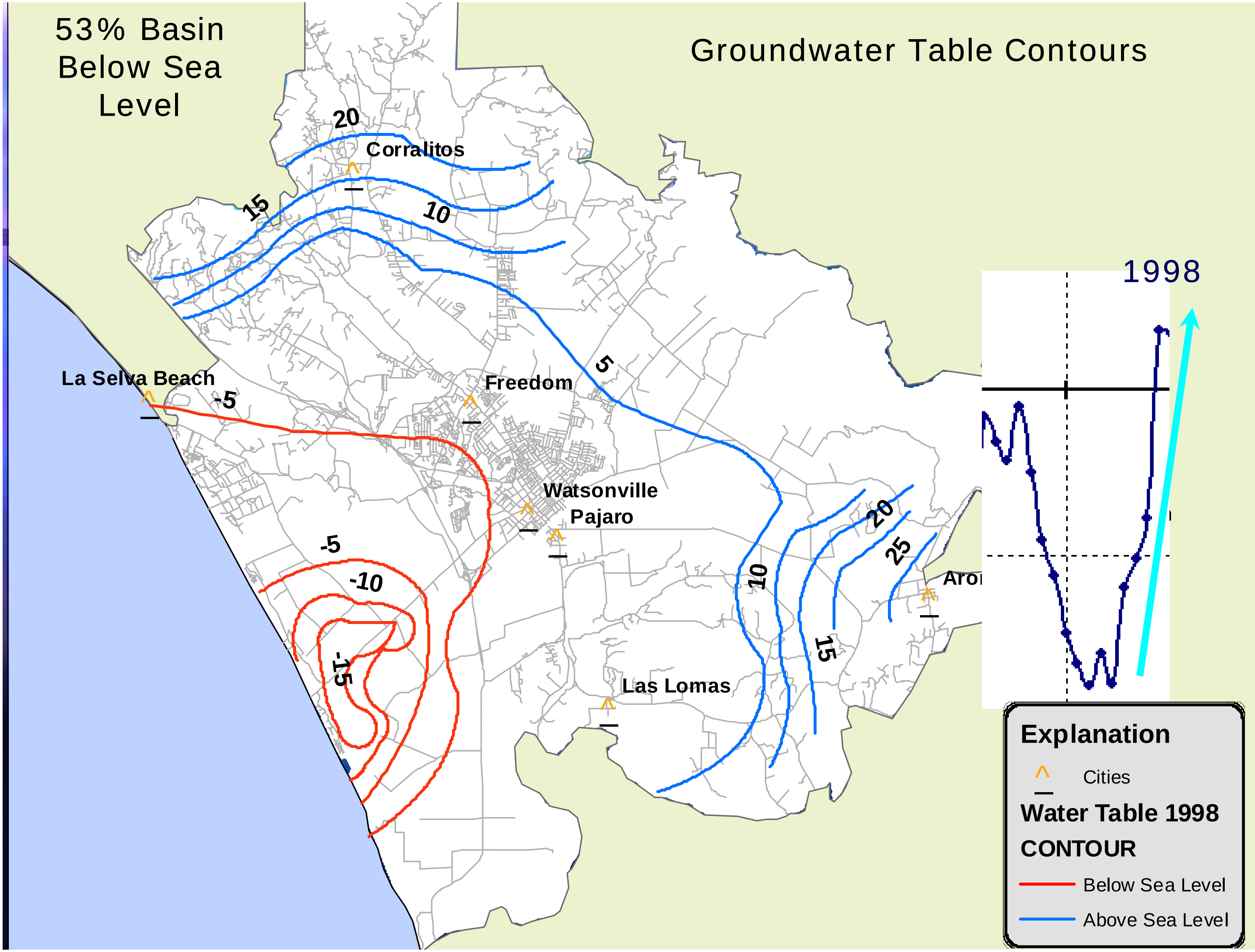
e 1992

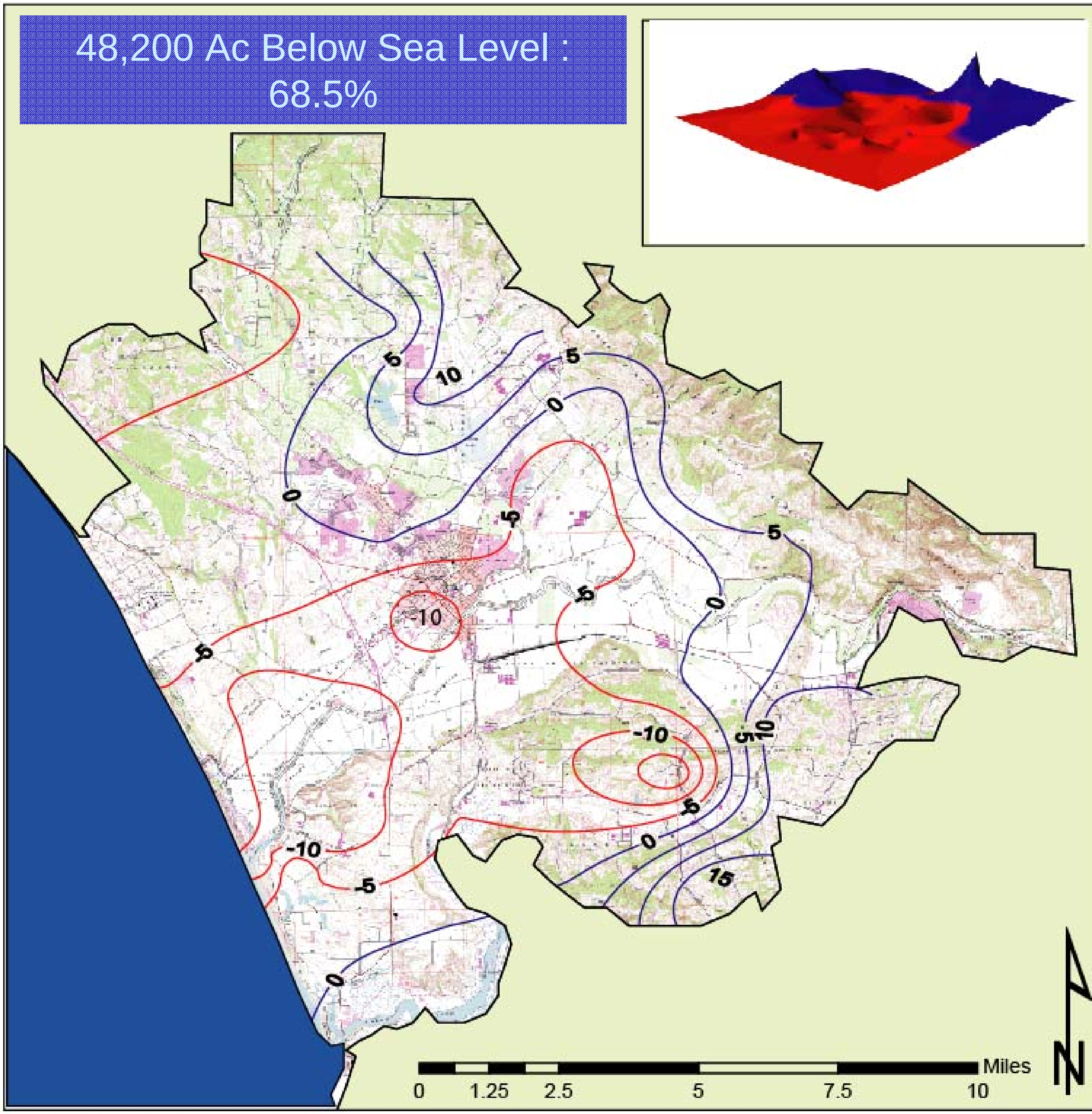
Sea Level

Sea Level


88% Basin Below Sea Level
Groundwater Table Contours
5
Corralitos
Accumulated Departure from Long-term Mean Precipitation
Percent of Accumulated Departure
300
200
100
0
-100
-200
-300
1870
1890
1910
1930
1950
1970
1990
2010
1992
e 1992
Sea Level
Sea Level

Groundwater Table Contours





Water Table Contour Map

September 2005

Explanation

Above Sea Level

Below Sea Level

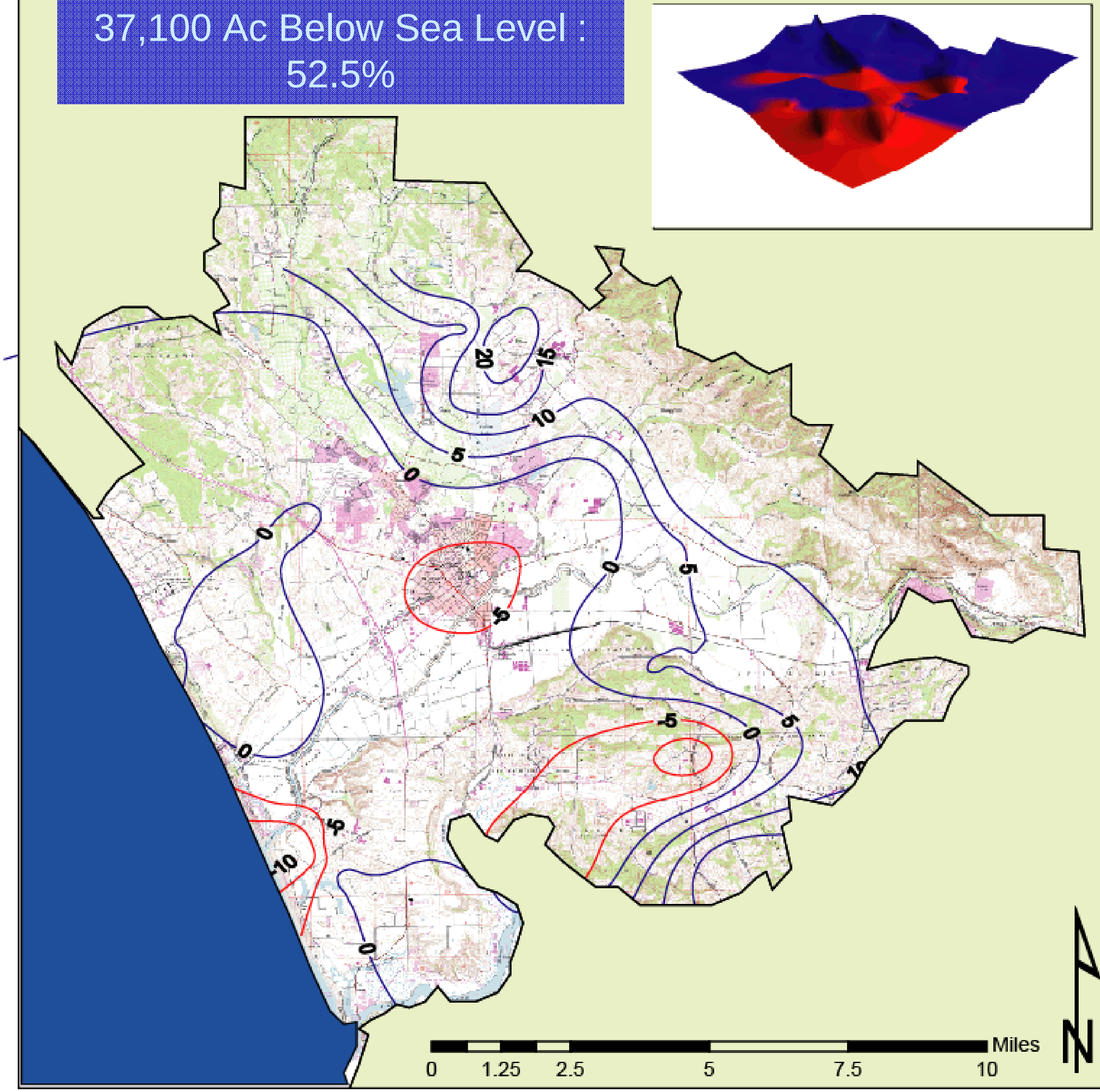
Contour Interval 5 Feet

Pajaro Valley Water Management Agency

37,100 Ac Below Sea Level : 52.5%

Water Table Contour Map

April 2005



Explanation

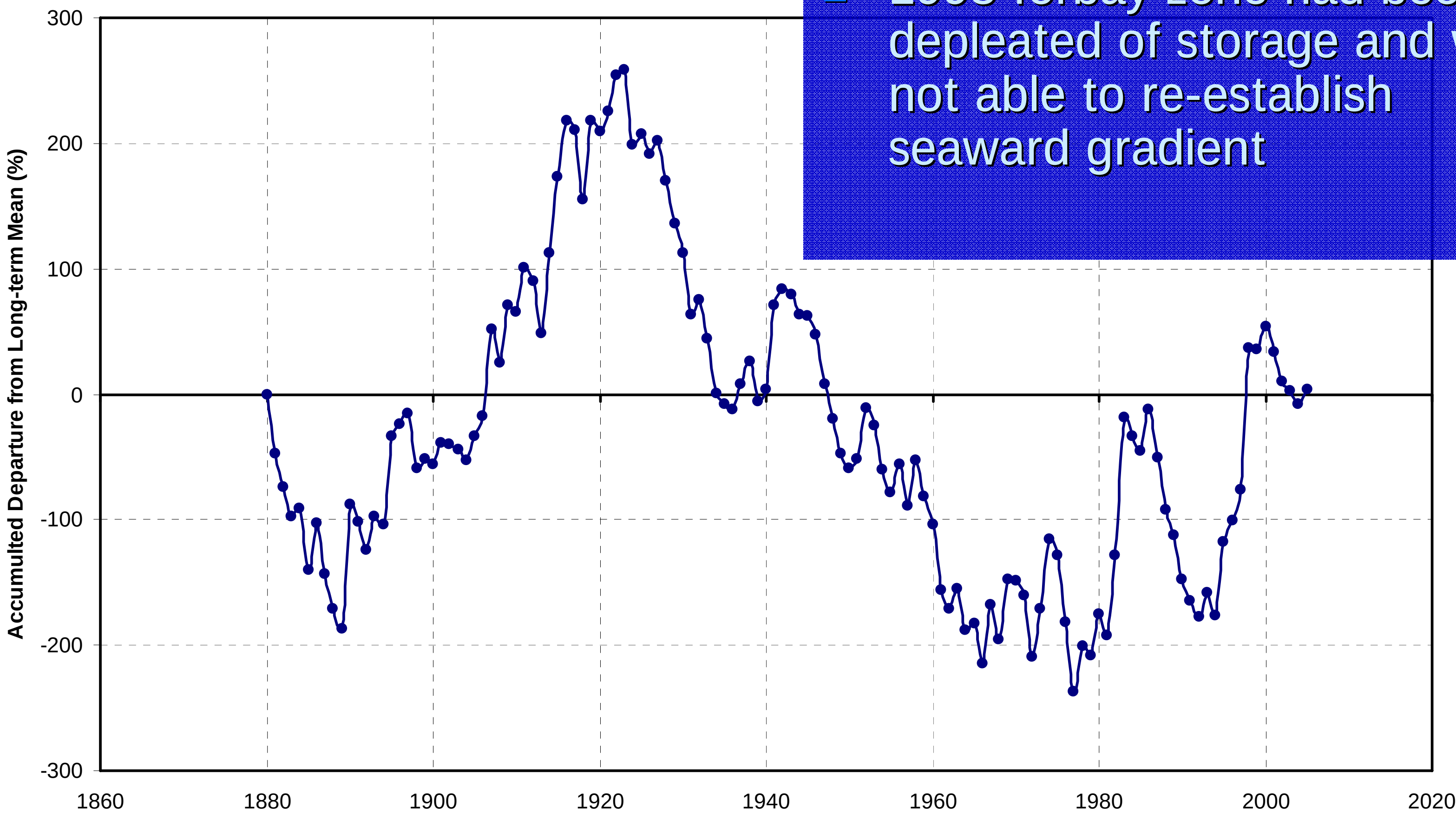
- Above Sea Level
- Below Sea Level

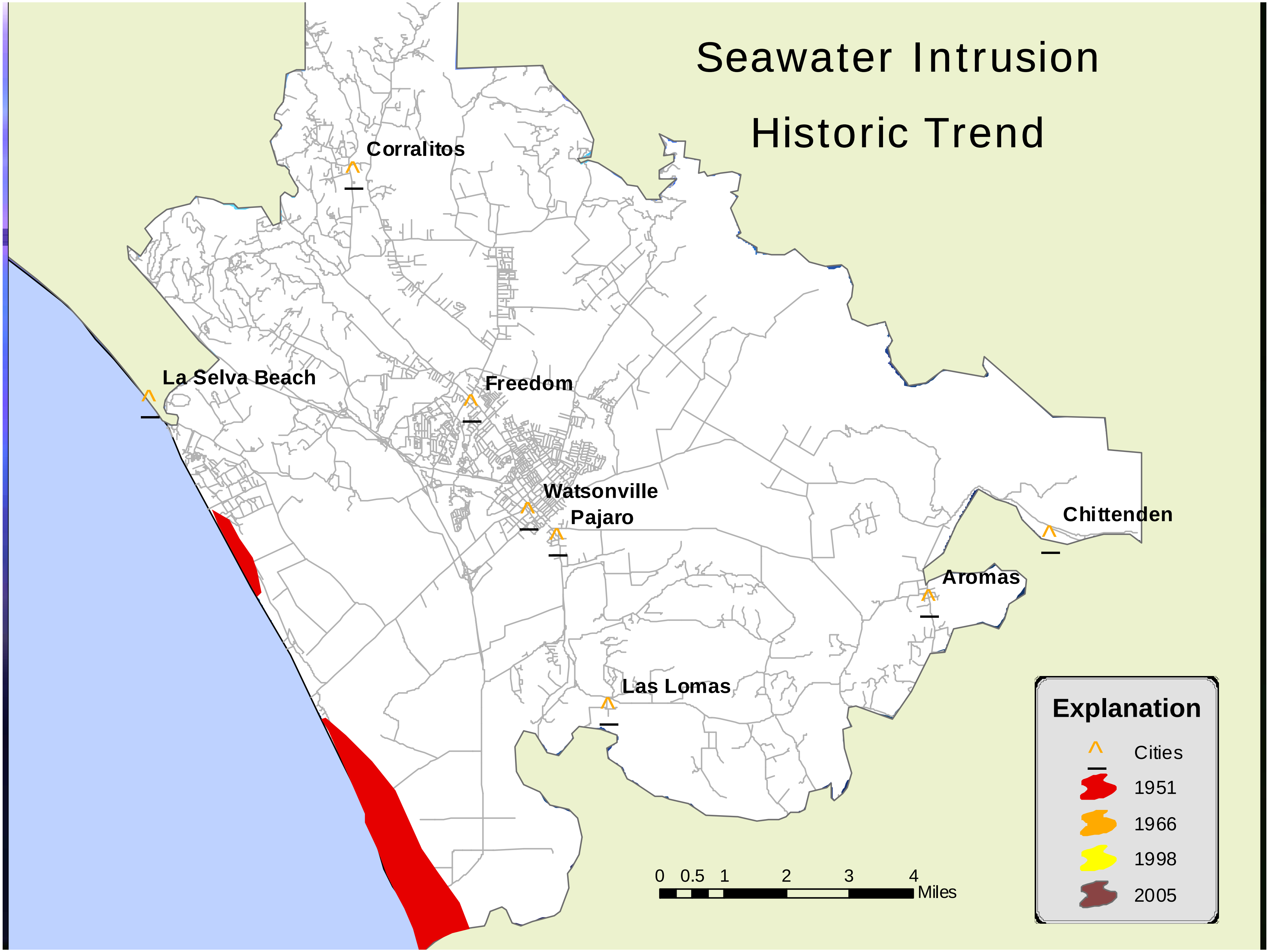
Pajaro Valley Water Management Agency

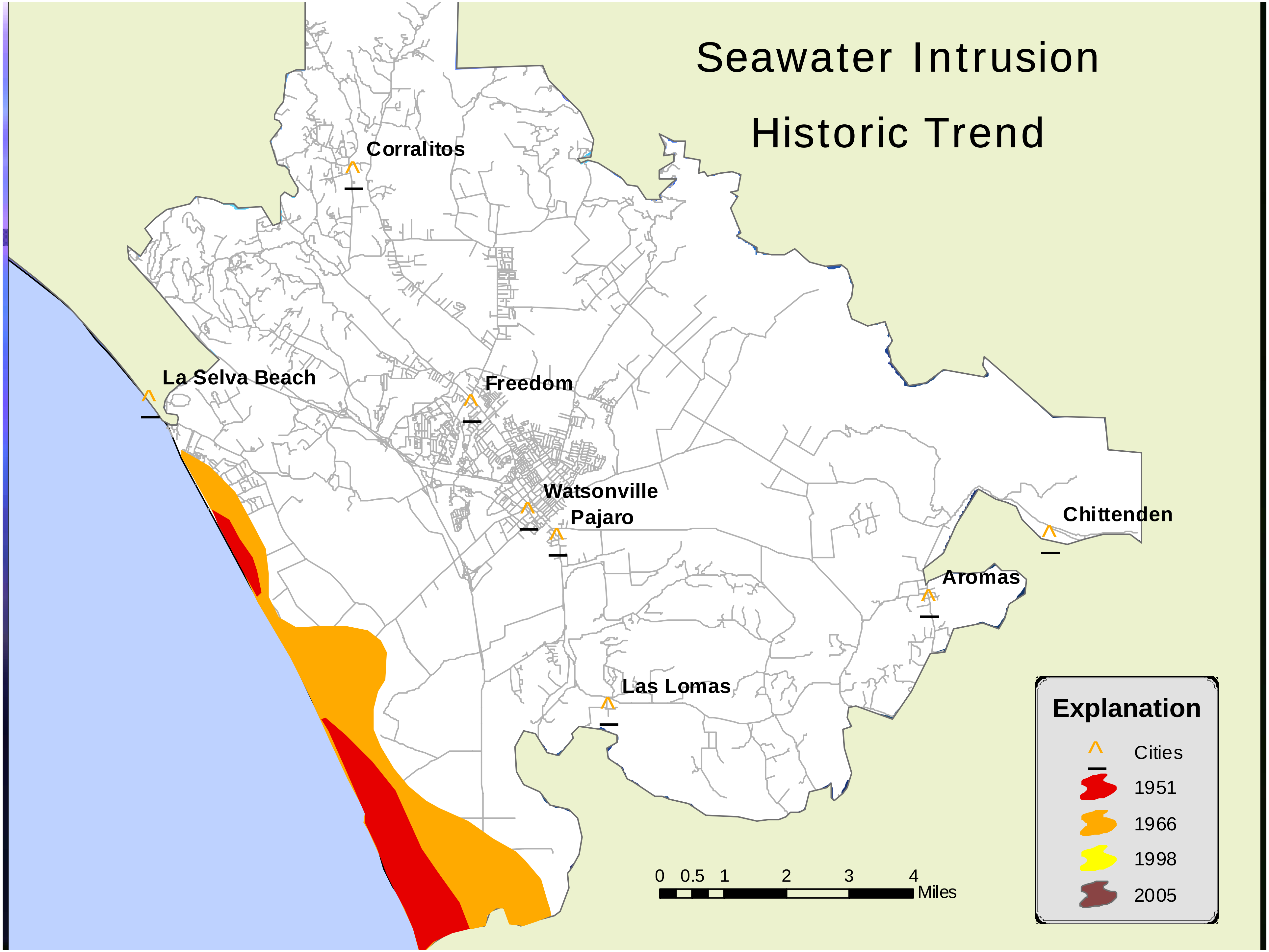
Water Level Response to Drought

	Drought	Post Drought
1950	9%	0%
1990	88%	48%
	April	September
2005	53%	69%

- 1951 Basin had enough storage in the forbay region to bring the pressure zone back above sea level and re-establish the gradient seaward
- 1998 forbay zone had been depleated of storage and was not able to re-establish seaward gradient




Seawater Intrusion
Historic Trend
Corralitos
La Selva Beach
Freedom
Watsonville
Pajaro
Chittenden
Aromas
Las Lomas
0 0.5 1 2 3 4
Miles
Explanation
Cities
1951
1966
1998
2005



Seawater Intrusion
Historic Trend
Corralitos
La Selva Beach
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0 0.5 1 2 3 4
Miles
Explanation
Cities
1951
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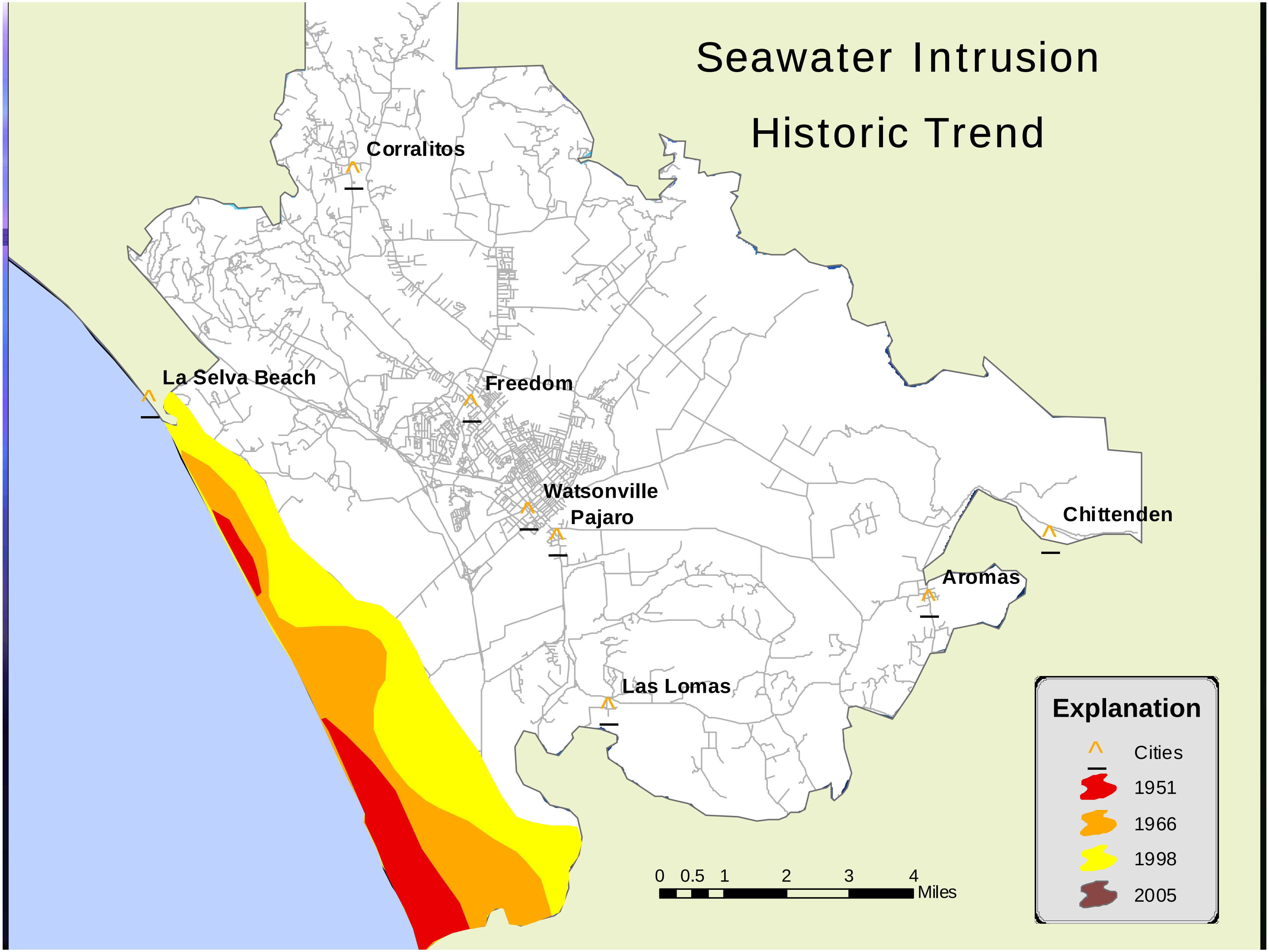
Seawater Intrusion
Historic Trend
Corralitos
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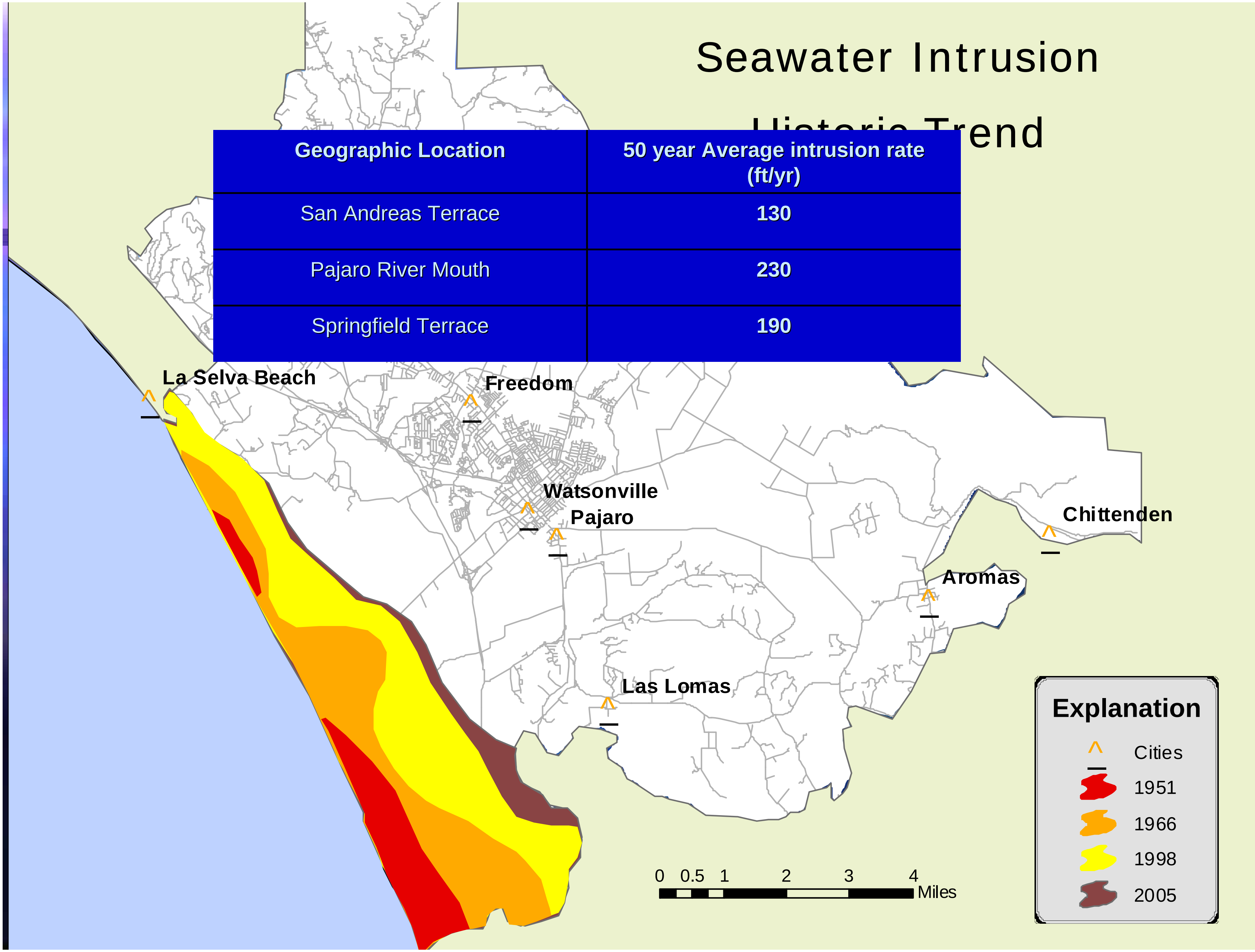
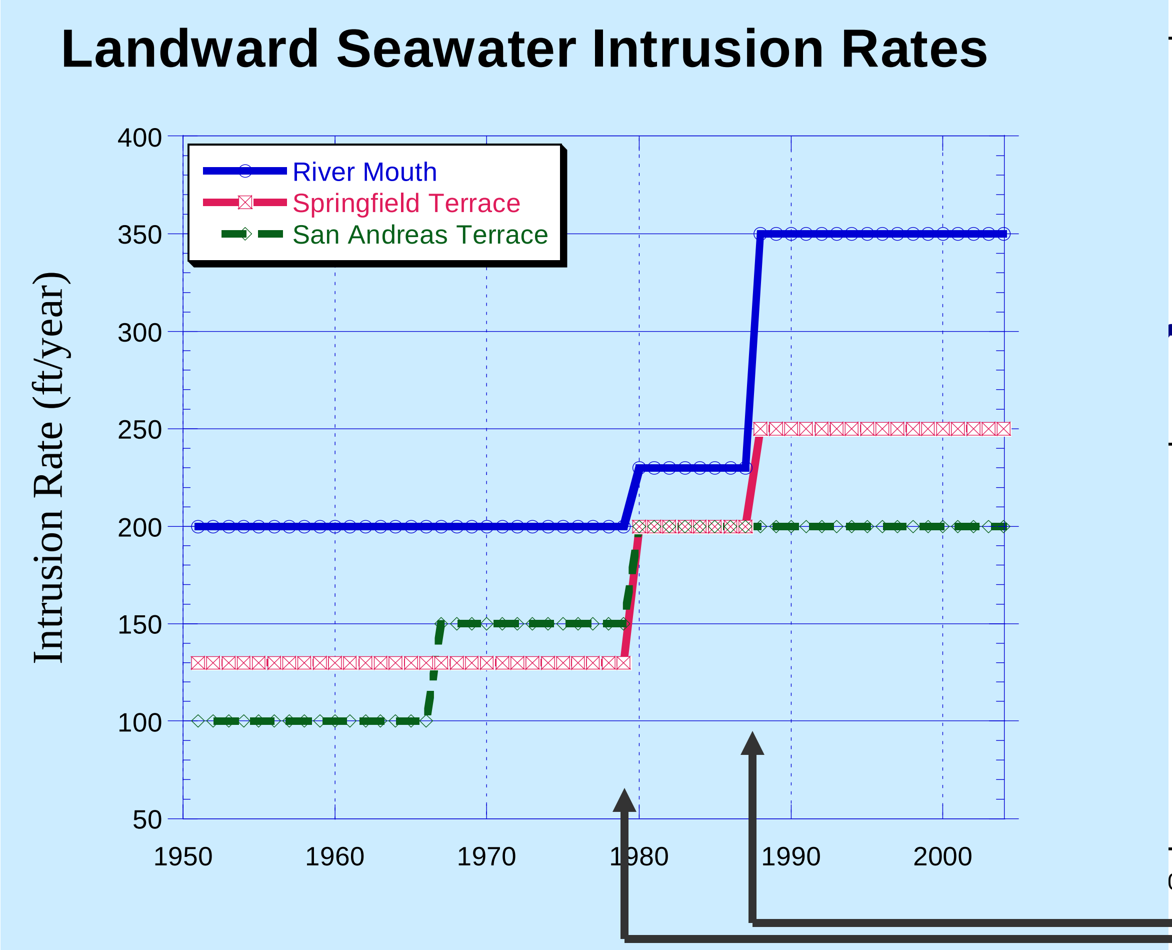
Freedom
Watsonville
Pajaro
Chittenden
Aromas
Las Lomas
0 0.5 1 2 3 4
Miles
Explanation
Cities
1951
1966
1998
2005

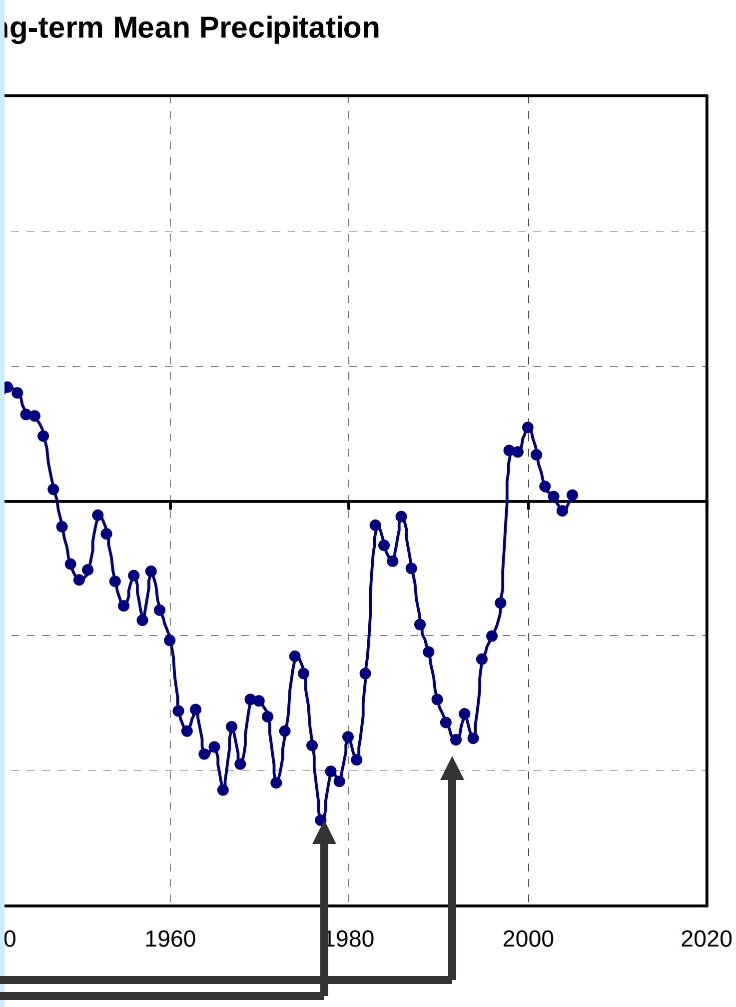
Seawater Intrusion Historic Trend

Geographic Location	50 year Average intrusion rate (ft/yr)
San Andreas Terrace	130
Pajaro River Mouth	230
Springfield Terrace	190

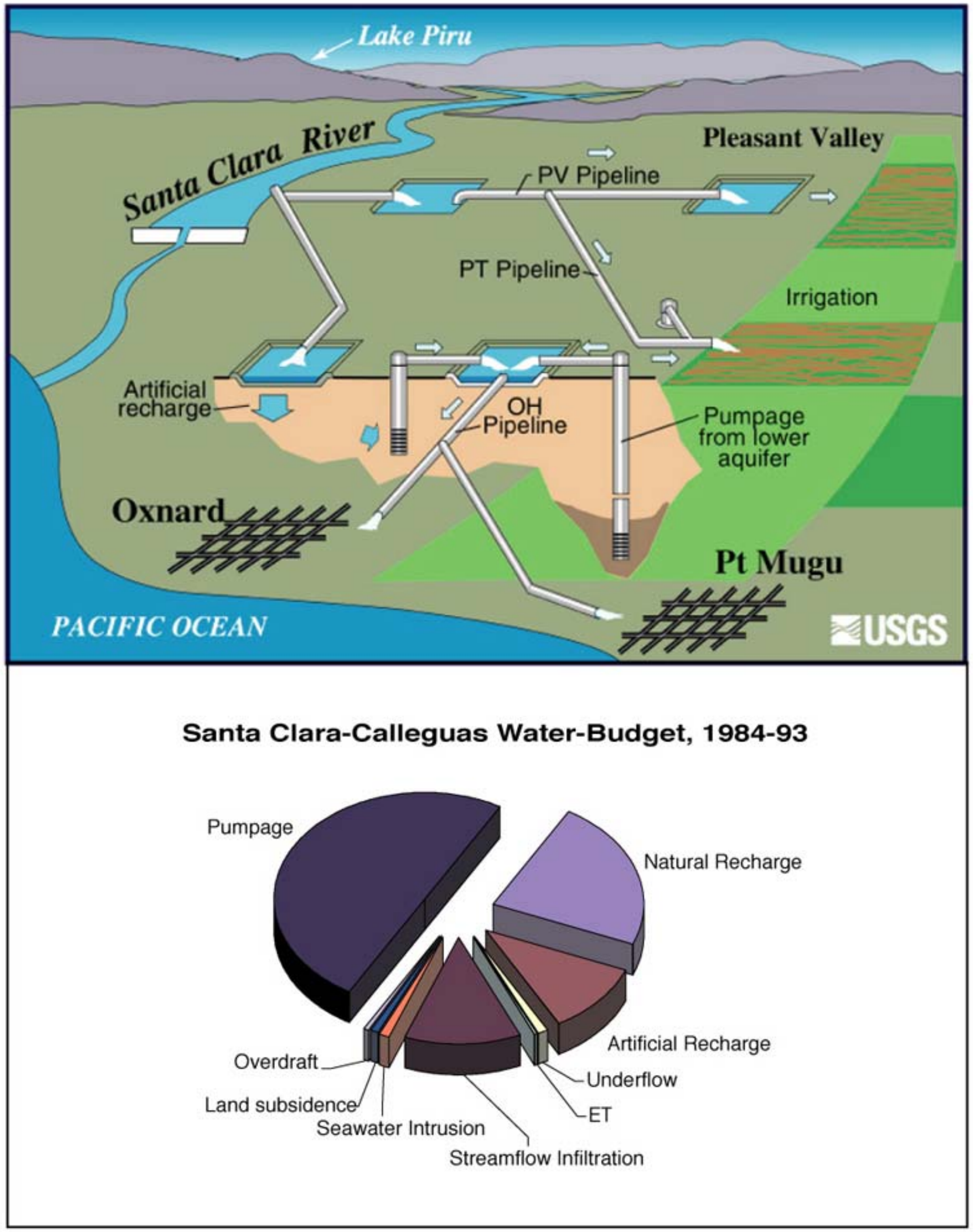


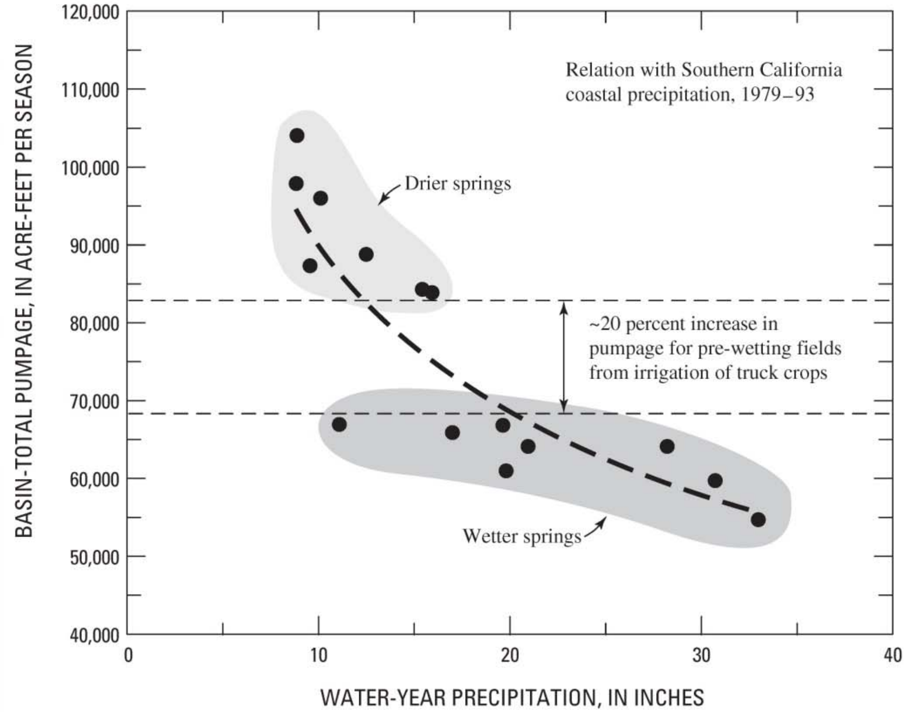
Seawater Intrusion Response to Drought





Santa Clara-Calleguas Water Resources



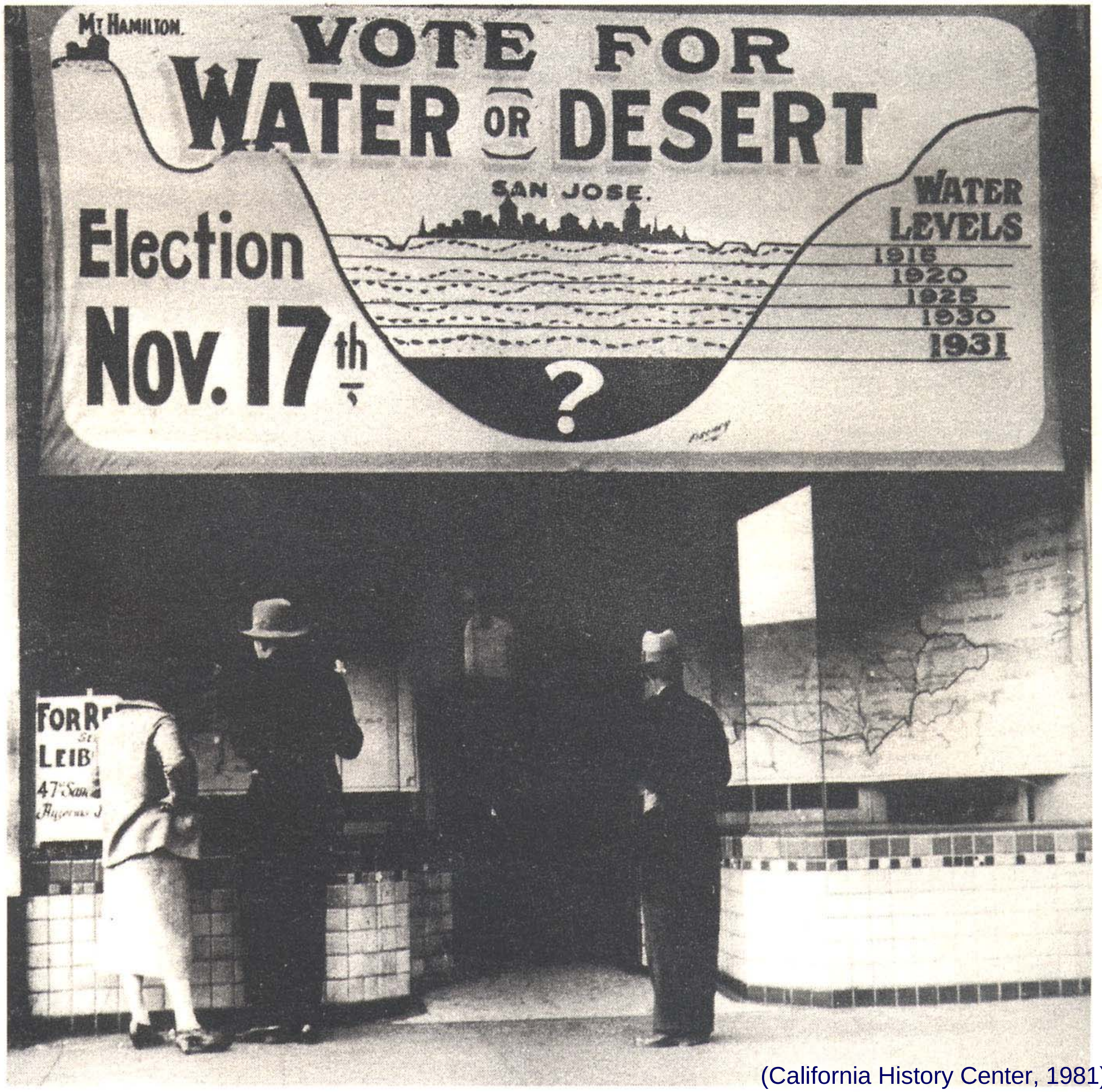


Complex Conjunctive Use still affected by climate variability/change

Figure 3.

Is the ground rising and falling?

Is there Land Subsidence?



(California History Center, 1981)

During the Great Depression, 1931 Statewide Election to raise $6 million for building system of dams and reservoirs recommended in 1921

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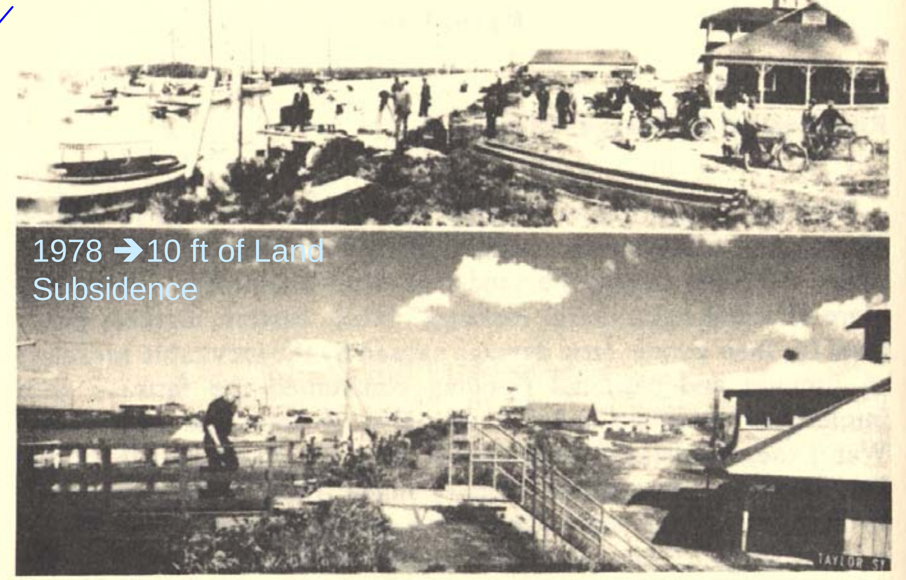
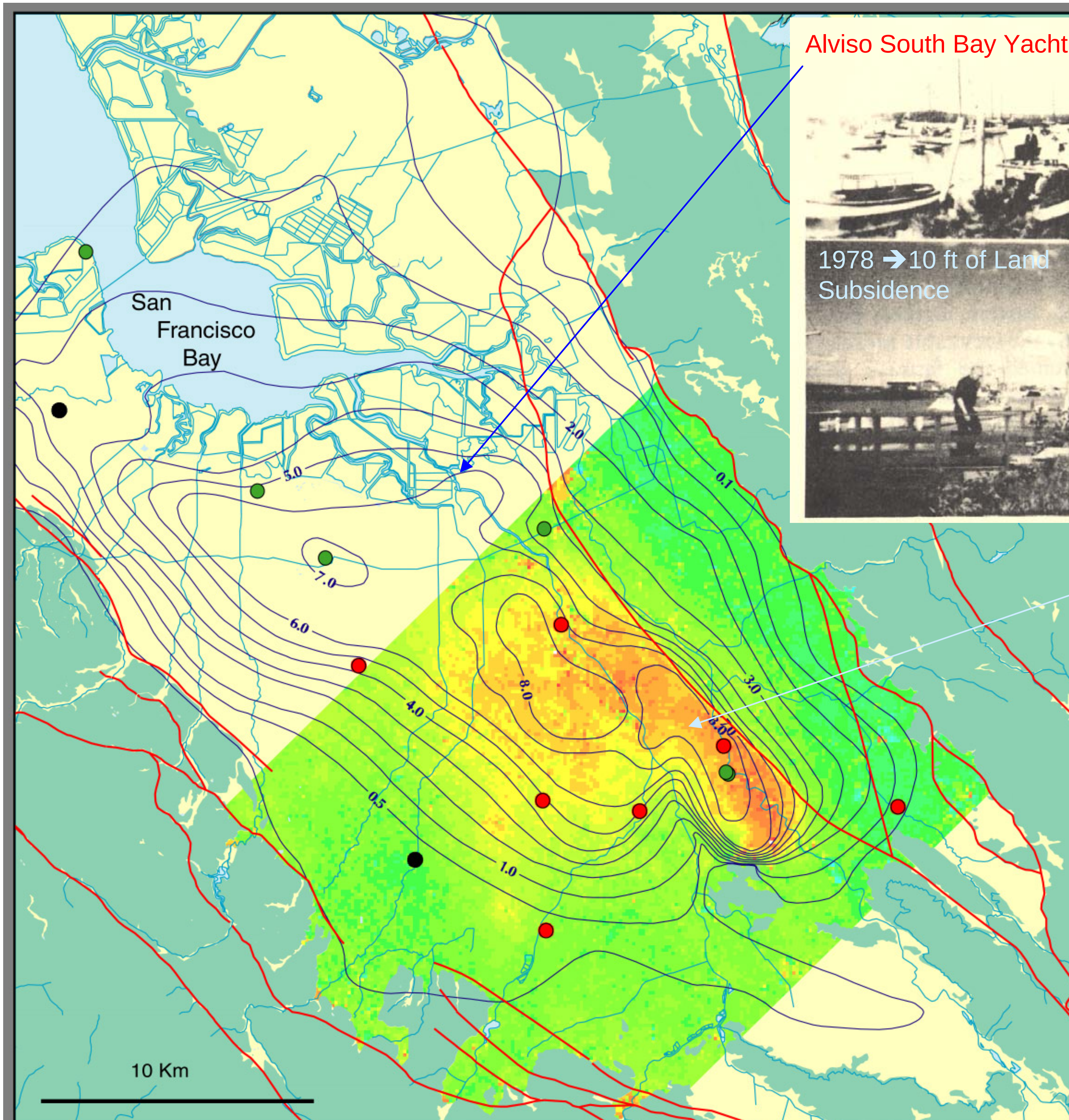
Alviso South Bay Yacht Club 1914

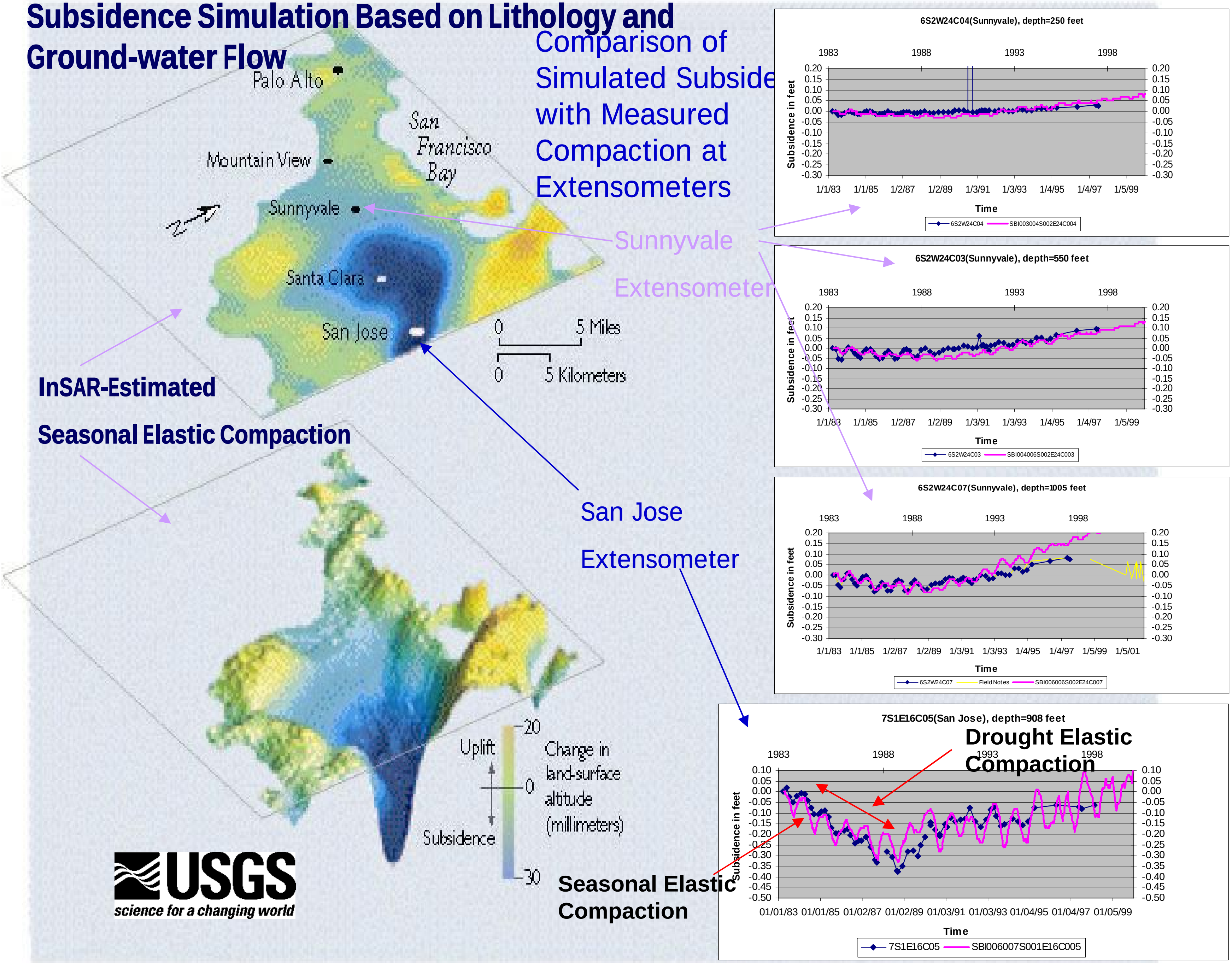
(California History Center, 198

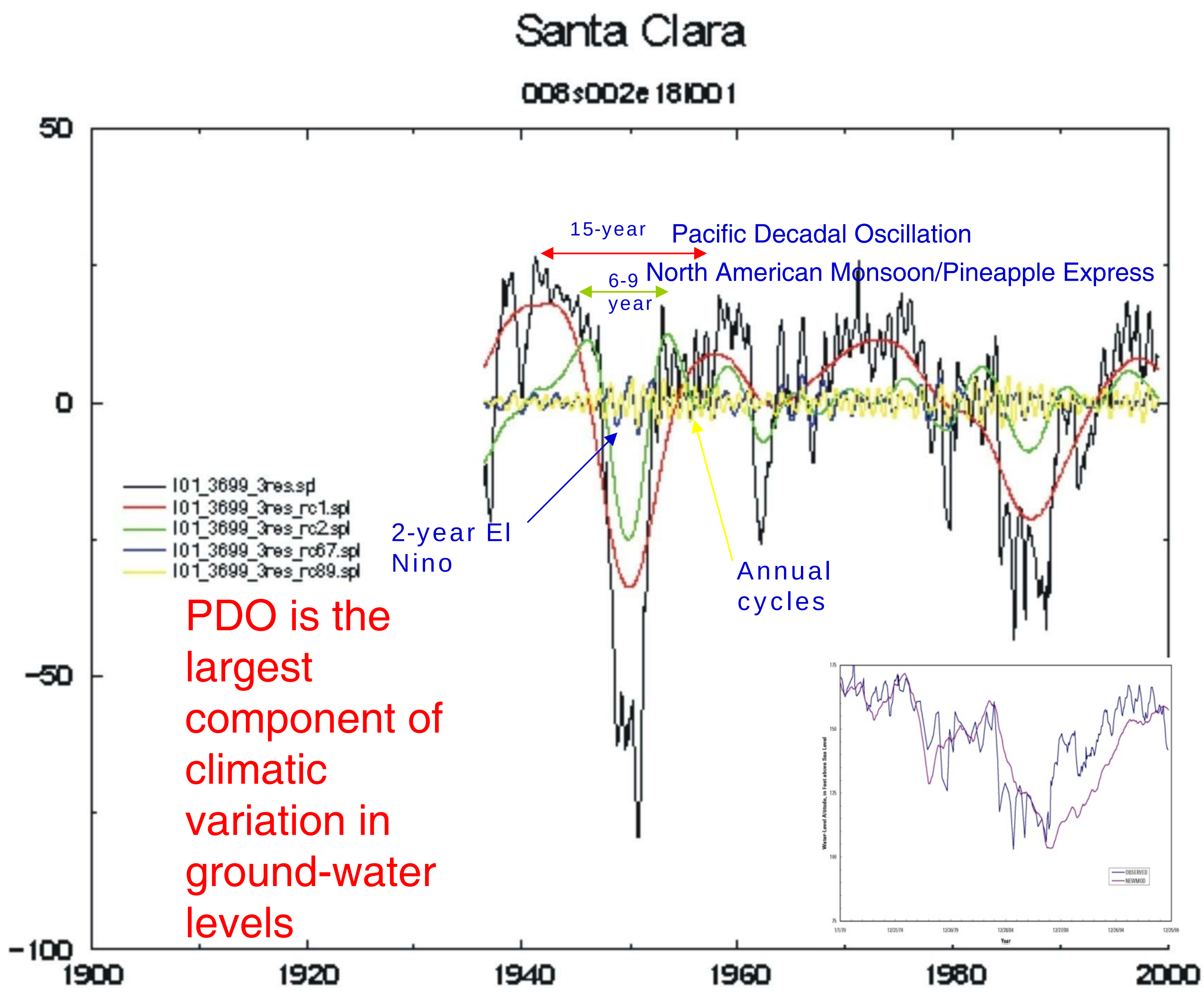




Poland's Contour map shows up to 13 ft of Land Subsidence in downtown San Jose. Recent InSAR deformation shows similar pattern

Subsidence Simulation Based on Lithology and Ground-water Flow

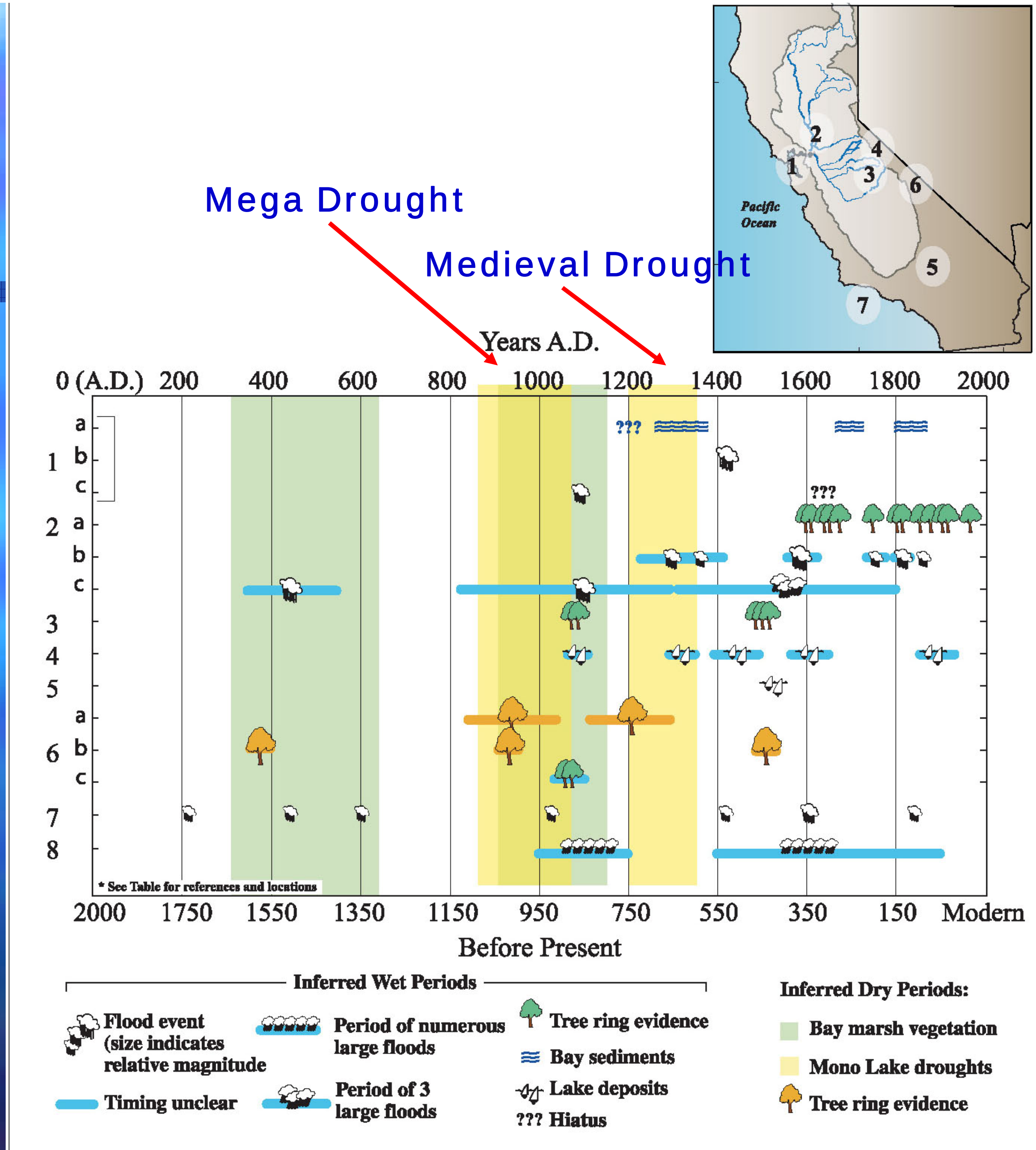




PDO is the largest component of climatic variation in ground-water levels

Paleo-Extreme Climate Events Central Valley, California

Mega-Droughts →



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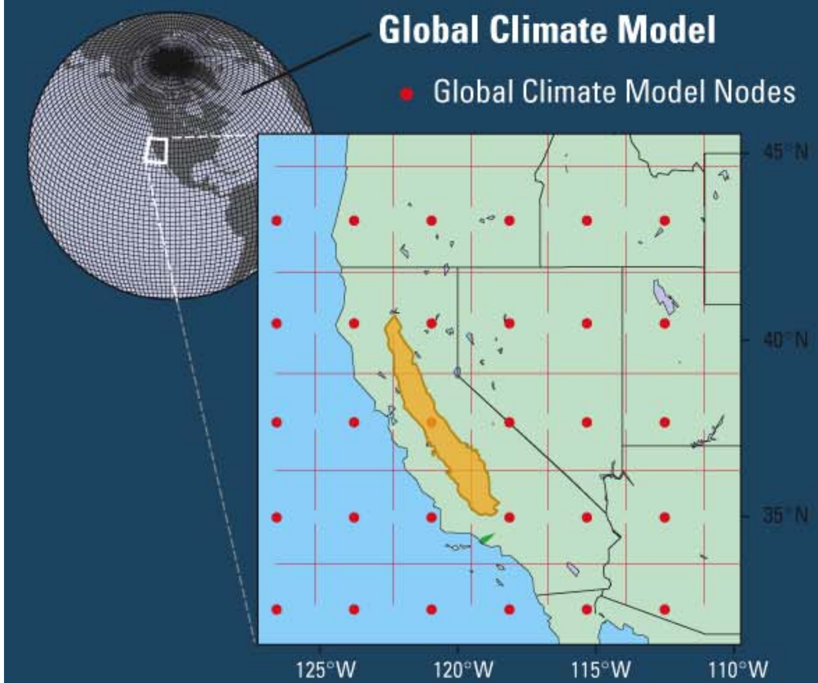


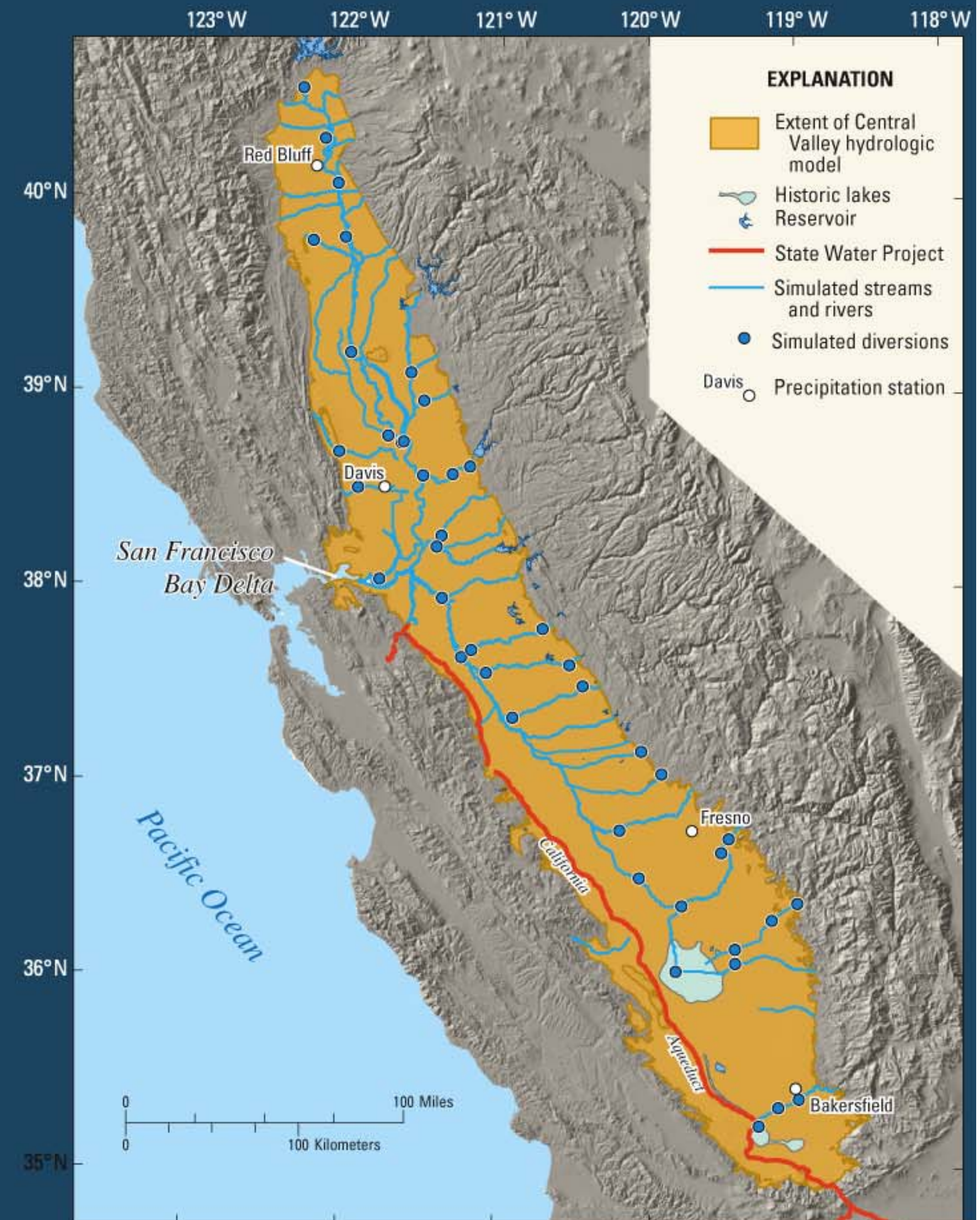


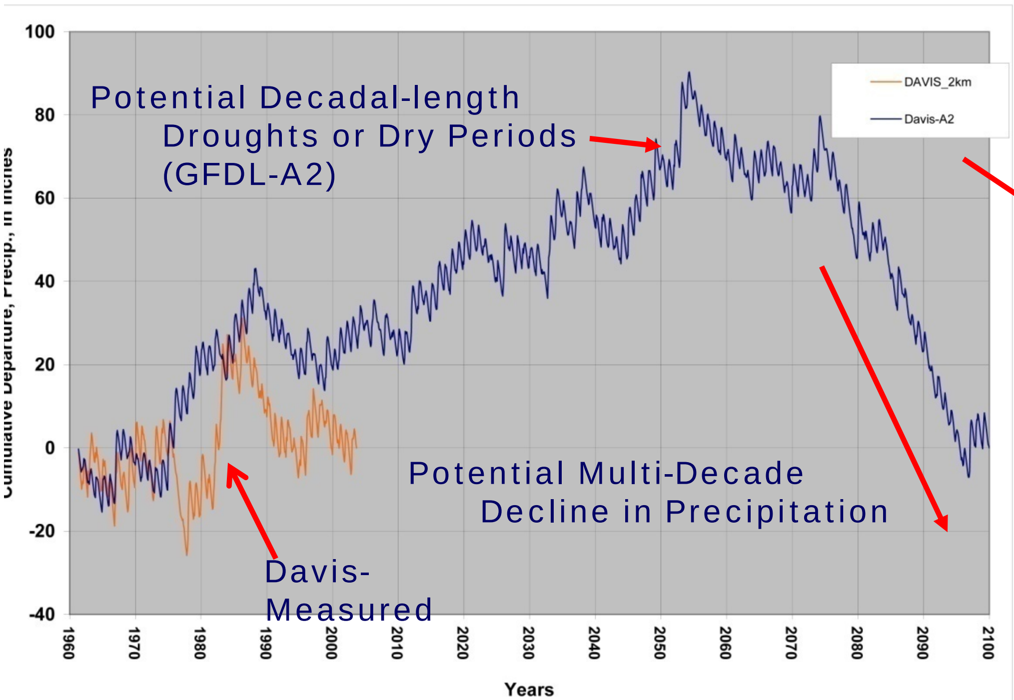
Figure 1. Map of Central Valley Hydrologic Model illustrating relation to the rivers, diversions, and San Francisco Bay Delta

Modified from Hanson and Dettinger, 2005; Faunt and others, 2008a (in review).

Precipitation Stationarity and Weak-Stationarity

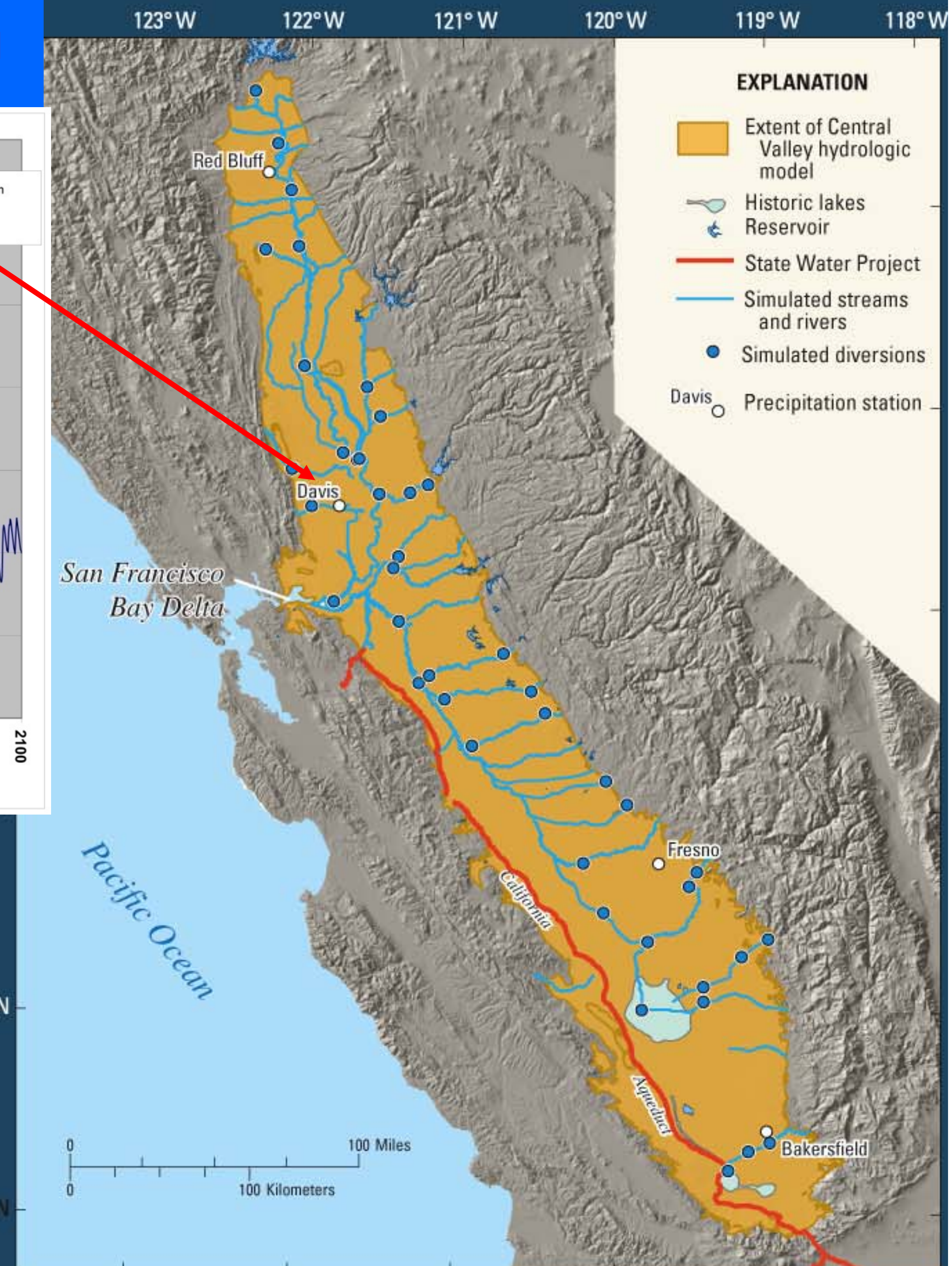
Cumulative Precipitation

Shows A2 Scenario at Davis with the potential for sustained droughts in the 21st Century



	Davis-Measured	Davis-GFDL/A2
	1917-2005	2006-2099
Mean	17.3 in	13.7 in
Variance	37.8 in²	19.4 in²
>PDO-AMO	43 yr (79%)	52 yr (87%)
PDO	18 yr (14%)	19 yr (10%)
MON-PE	9 yr (3%)	9 yr (2%)
ENSO	2 – 6 yr (4%)	2 – 6 yr (1%)

Modified from Hanson and Dettinger, 2005; Faunt and others, 2008a (in review).



Coastal Climate Change/Variability Conclusions

- Geologic structures control flow and connectivity in coastal aquifers
  - ➔Submarine Canyons and proximity to Offshore Outcrops
- Seawater Intrusion can occur with Land Subsidence and Coastal Flooding
- Climate cycles drive supply (Recharge/Streamflow) and demand components (Land Use/Pumpage) that affect seawater intrusion/land subsidence/flooding (seasonal ➔ decadal)
- Climate change may also represent changes in variability of climate cycles (?) ➔ Needs further investigation
- Downscaling and use of GCMs in island & coastal regions still problematic ➔ fog, orographic effects of smaller-scale mountains, etc.


THANKS → QUESTIONS & DISCUSSION ?
OUND-WATER SUSTAINABILITY = STRAWBERRY FIELDS FOREVER ??
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